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Clarendon Press Series.

A HANDBOOK OF DESCRIPTIVE ASTRONOMY.

Frederick

BY

GEORGE F. CHAMBERS, F.R.A.S.

OF THE INNER TEMPLE, BARRISTER-AT-LAW:

Author of "A Digest of the Law relating to Public Health;"
"A Popular Summary of Public Health Law;"
"A Digest of the Law relating to Public Libraries and Museums;"
and other Works.

"The heavens declare the glory of God; and the firmament sheweth his handywork."
Psalm xix. 1.

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PREFACE TO THE THIRD EDITION.

ADVANTAGE has been taken of the call for a new edition of this work to subject the whole, from the first page to the last, to a searching revision. This has proved to be a task of unusual difficulty and labour, in consequence of the astonishing developement which has taken place in the science of Astronomy during the last ten years. I might, however, have had a better chance of grappling with this had I not laboured for a long time past under serious disadvantages arising out of the demands on my time made by professional work, which have of late been such as to render it very difficult for me to give to Astronomical Studies that close attention which is indispensable if the author of an Astronomical Book would keep his pages up to date and so do justice alike to himself and his readers. It is not open to doubt that this is a matter which sits very lightly upon the consciences of some writers of Text-books.

I do not know that it is worth while to attempt to specify at any great length what has been done in preparing this Edition. It may be stated, however, that there is scarcely a single page which has not been, to a greater or less extent, dressed up, or in some way amended, with the object of making its statements more accurate in substance or intelligible in diction. The most important changes will be found in the chapters dealing with the Sun, Sidereal Astronomy, and Astronomical Instruments. The descriptions of Clusters and Nebulæ have been made more numerous, and the lists of objects critically revised one by one actually at the telescope, so as to make that portion of the work more completely than formerly a *vade mecum* for the mere star-gazer who is an Astronomer simply in the respect that he is the owner of a telescope. Indeed, it has been chiefly with this idea in view that so much additional matter

has been introduced into the chapters relating to Astronomical Instruments. The "Practical Hints" and suggestions have been gathered from so many sources, and embody the collective wisdom and experience of so many men, that they cannot fail to deserve attention. I believe also that this volume now stands alone in its full description, so far as regards the wants of amateur observers, of the mounting and use of Reflecting Telescopes.

The present edition extends to 961 pages as against 856 in the case of the last edition, but these figures quite fail to convey an idea of the amount of the new matter now given, because large type has been in many places replaced by small type and blank backs of Plates occupied by type, so that the net increase in the contents of the volume is not less than 200 pages.

I have to acknowledge a great amount of very useful advice and assistance from observers in all parts of the world, most of them total strangers to me, many of them being persons I had never heard of until the receipt of their letters. Indeed, the letters that I have received, especially from the United States of America, have been a very gratifying encouragement to me to persevere in improving this work in every possible way.

At the risk of being invidious, I must tender my particular thanks to the Rev. *R. Main*, of the Radcliffe Observatory, Oxford; Prof. *A. S. Herschel*, of Newcastle; Mr. *W. T. Lynn*, F.R.A.S., and Mr. *E. W. Maunder*, F.R.A.S., both of the Royal Observatory, Greenwich; Capt. *Noble*, F.R.A.S., Mr. *G. Knott*, F.R.A.S., and Mr. *J. Browning*, F.R.A.S., in the United Kingdom; and abroad to MM. *E. Schönfeld*, of Bonn; *R. Wolf*, of Zurich; Mr. *J. N. Lewis*, of Mount Vernon, Ohio, U.S.; and Mr. *N. Pogson*, Government Astronomer at Madras. Much material literary assistance of a non-astronomical character has been afforded me by Mr. *H. J. Hood*, of the Equity Bar, whilst for some of the illustrations I am indebted to the Secretaries of the Royal Astronomical Society, Mr. *J. N. Lockyer*, and *Macmillan and Co.*

G. F. C.

East Bourne, Sussex,
December, 1876.

PREFACE.

ASTRONOMY is not cultivated in this country, either as a study or as a recreation, to the extent that it is on the Continent of Europe and in America. I am not exactly prepared to say why this should be so, but perhaps a clue can be found. There is a lack of works in the English language which are at one and the same time attractive to the general reader, serviceable to the student, and handy, for purposes of reference, to the professional Astronomer; in fact, of works which are popular without being vapid, and scientific without being unduly technical.

The foregoing observations will serve to indicate why this book has been written. Its aim, curtly expressed, is, general usefulness.

Preferring facts to fancies, I have confined within very moderate limits Theoretical considerations, and especially have I avoided chronicling any of those mischievous speculations on matters belonging to the domain of Recondite Wisdom, which have within the last few years borne such pernicious yet natural fruits.

Great pains have been taken to present the latest information on all branches of the Science. Astronomical progress is usually so rapid, that unless an author exercises constant vigilance, a book will soon fall behind the times. In regard to this matter of bringing up to date, it is believed that the present volume will compare favourably with any of its contemporaries.

To Mr. *I. Fletcher*, M.P., Mr. *W. De La Rue*, Mr. *J. Nasmyth*, Mr. *J. Murray*, Dr. *C. A. F. Peters*, the Secretaries of the Royal Astronomical Society, and the Editors of the *Popular Science Review* and *Astronomical Register*, I am indebted for divers facilities in regard to the illustrations.

The Woodcuts have mostly been executed under my own personal superintendence, but those of the Clusters and Nebulæ are not all to my satisfaction. It has been very difficult to prevent the Engraver from unduly exaggerating the brilliancy of the stellar details.

Perhaps this is a fitting place to draw attention to a matter of some importance in connection with Sir *John Herschel's* very numerous drawings of Clusters and Nebulæ. It does not appear to be generally known that they are all reversed right and left, and the consequence is, that unless allowance is made for the reversal, when comparisons are instituted, either with the objects themselves or with the figures of other observers (who, so far as I have noticed, invariably represent the objects as they are seen through an inverting telescope), the reader will find it impossible to reconcile the discrepancies which manifest themselves.

Every care has been taken to secure accuracy in the printing, and I trust that the errors which may have escaped notice are neither numerous nor important.

Finally, I hope that this book may be the means of inducing some, at least, to interest themselves in the study of that noble, but by no means abstruse, Science which in so conclusive a manner shews forth the wonderful Wisdom, Power, and Beneficence of the Great Creator and Omnipotent Ruler of the Universe.

G. F. C.

March, 1867.

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ADDENDA ET CORRIGENDA.

Page

12, line 9, *for* $24^h\ 14^m\ 59^s$ *read* $25^d\ 5^h\ 37^m$.

71, line 5 from bottom of text, *for* "discovered by Sir G. B. Airy in 1846" *read* "first surmised by Sir G. B. Airy about 1828, and fully expounded in 1831. See *Phil. Trans.*, 1828 and 1832."

87. *For* "Sept. 21" *read* "about Sept. 23."

97. Observers interested in Mars should consult a most interesting and valuable memoir entitled *Areographie* presented to the Academie Royale de Belgique in June, 1874, by M. F. Terby of Louvain. It reached me too late to be mentioned in the text.

98, line 9 from bottom, *for* "one conjunction and one opposition" *read* "two conjunctions or two oppositions."

105, line 4. The minor Planet *Hilda* is more distant than *Freia*.

110, line 10 from bottom, *after* "planet" *insert* "except Saturn."

124, paragraph 4. A letter from Mr. Barneby, received too late to be made use of in preparing p. 124 for press, has cleared up the difficulties noted in this paragraph. In line 5 "third" is a misprint by the R. A. Society's printer for "first."

127, line 9 from bottom, *for* "synodical" *read* "sidereal."

129, footnote (*t*), *for* 185,500 *read* 186,660.

129, line 1 of note (*t*), *for* "reduction" *read* "augmentation."

148. By an oversight no mention is made of Prof. J. C. Maxwell's highly important essay on *The Stability of the Motion of Saturn's Rings*, published at Cambridge in 1859. See *Month. Not.*, vol. xix. p. 297.

169. Prof. Newcomb has informed me by letter that Hind's elements of the satellite of Neptune, "at least ☊ and ι, are far wrong."

235, line 5, *for* $8105\frac{1}{2}$; $8121\frac{1}{2}$; $8105\frac{1}{2}$; *read* $8{,}105\frac{1}{2}$; $8{,}121\frac{1}{2}$; $8{,}105\frac{1}{2}$.

297. Some conclusions by Von Asten respecting Encke's Comet should have been noted. He finds that inexplicable irregularities in the motion of the Comet were manifested in 1875, whilst in 1868 there were no such irregularities traceable. He deems the

Page

"Resisting Medium" theory only partially sufficient, and falls back upon an opinion of Bessel's that the remarkable disturbances to which this Comet is subject have their origin in the internal constitution of the Comet. (*Ast. Nach.*, vol. lxxxv. No. 2038. May 25, 1875.)

546, line 20. Wolf considers that the Merope nebula is variable with a short period. As regards the Stars in the Pleiades generally he thinks *Merope* and *Atlas* to be decidedly variable, and *Maia* perhaps so. (*Month. Not.*, vol. xxxvi. p. 196. Feb. 1876.)

736, line 30. In the remarks on Astronomical Periodicals the following sentence was omitted:—"The Germans have a somewhat similar periodical called *Sirius; Zeitschrift für populäre Astronomie*, edited by R. Falb and published by C. Scholtze, Leipzig, about 9*d*. monthly, delivered in England."

THE GREEK ALPHABET.

*** The small letters of this alphabet are so frequently employed in Astronomy that a tabular view of them, together with their pronunciation, will be useful to many unacquainted with the Greek language.

α Alpha.	ν Nu.
β Beta.	ξ Xi.
γ Gamma.	ο O-mīcron.
δ Delta.	π Pi.
ε Epsīlon.	ρ Rho.
ζ Zēta.	σ Sigma.
η Eta.	τ Tau.
θ Theta.	υ Upsīlon.
ι Iota.	φ Phi.
κ Kappa.	χ Chi.
λ Lambda.	ψ Psi.
μ Mu.	ω O-mega.

BOOK I.

THE SUN AND PLANETS.

CHAPTER I.

THE SUN. ☉

"O ye Sun and Moon, bless ye the LORD: praise Him, and magnify Him for ever."—*Benedicite.*

Astronomical importance of the Sun.—Solar parallax.—The means of determining it.—By observations of Mars.—By Transits of Venus.—Numerical data.—Light and Heat of the Sun.—Gravity on the Sun.—Spots.—Description of their appearance.—How distributed.—Their duration.—Effect of the varying position of the Earth with respect to the Sun.—Their size.—Instances of large Spots visible to the naked eye.—The Great Spot of October 1865.—*Their periodicity.—Discovered by Schwabe.—Table of his results.—Curious connexion between their periodicity and that of other physical phenomena.—Singular occurrence in September* 1859.—*Wolf's researches.—Spots and Terrestrial Temperatures.—Their Physical Nature.—The Wilson-Herschel Theory.—Historical Notices.—Scheiner.—Faculæ.—Luculi.—Nasmyth's observations on the character of the Sun's Surface.—Huggins's ditto.—Ballot's inquiry into Terrestrial Temperatures.*

IF there is one celestial object more than another which may be regarded as occupying the foremost place in the mind of the astronomer, it is the Sun: for, speaking generally, there is scarcely any branch of astronomical inquiry with which, directly or indirectly, the Sun is not in some way associated. It will not therefore appear unreasonable if we deal with it at the very commencement of a treatise on Descriptive Astronomy[a].

By common consent, the mean distance of the Earth from the Sun is taken as the usual unit of astronomical measurement.

The most approved method of determining the value of this is

[a] Every one who wishes thoroughly to "get up" the Sun should read Secchi's magnificent work *Le Soleil*, of which a second and much enlarged edition was published in 1875.

(as was first pointed out by Halley) by the aid of observations of transits of the planet Venus across the Sun, (to be dealt with generally hereafter). The problem is, for various reasons, an intricate one in practice, but when solved places us in possession of the amount of the Sun's *equatorial horizontal parallax;* in other words, gives us the angular measure of the Earth's equatorial semi-diameter as seen from the Sun's centre, the Earth being at its mean distance from the Sun. With this element given, it is not difficult to determine, by trigonometry, the Sun's distance, expressed in radii of the Earth; reducible thereafter to miles.

Encke, of Berlin, executed an able discussion of the observations of the transit of Venus in 1769, and deduced 8·5776″ as the amount of the angle in question[b]. From this it would appear that the mean distance of the Sun from the Earth is 24046·9 times the equatorial radius of the former (3962·81 miles), equal to 95,293,055 miles, but these results, excellent as they were thought to be, ceased some years ago to command the acceptance of astronomers.

At a meeting of the Royal Astronomical Society, on May 8, 1857, Sir G. B. Airy proposed to revive a suggestion of Flamsteed's[c] for determining the absolute dimensions of the solar system, founded upon observations of the displacement of Mars in right ascension, when it is far east of the meridian and far west of the meridian, as seen at a single observatory; such observations to commence a fortnight before and to terminate a fortnight after the Opposition of the planet. In consequence of the great eccentricity of the orbit of Mars, this method is only applicable to those Oppositions during which the planet is nearly at its least possible distance from the Earth. Airy pointed out the advantages of this method in the various respects that Mars may then be compared with stars throughout the night; that it has two observable limbs, both admitting of good observation; that it remains long in proximity to the Earth; and that the nearer it is, the more extended are the hours of observation, in all of which matters Mars offers advantages over Venus for observations of displacement in Right Ascension. Airy also entered into some considerations relative to certain of the forthcoming Oppositions, and named

[b] *Der Venusdurchgang von* 1769, p. 108. Gotha, 1824.
[c] Baily, *Life of Flamsteed*, p. 32.

those of 1860, 1862, and 1877, as favourable for determining parallax in the manner he suggested[d].

Another astronomer now appears on the scene. M. Le Verrier announced in 1861[e] that he could only reconcile discrepancies in the theories of Venus, the Earth, and Mars, by assuming the value of the solar parallax to be much greater than Encke's value of 8·5776″. He fixed 8·95″ as its probable value, though, as Stone has pointed out, this conclusion taken by itself rests on a not very solid foundation[f].

The importance of a re-determination was thus rendered more and more obvious, and Ellery, of Williamstown, Victoria, New South Wales, succeeded in obtaining a fine series of meridian observations of Mars, at its Opposition in the autumn of 1862, whilst a corresponding series was made at the Royal Observatory, Greenwich. These were reduced by Stone, and the mean result[g] is a value of 8·932″ for the solar parallax, with a probable error of only 0·032″, supposing the probable error of a single observation to be 0·25″. This result is singularly in accord with Le Verrier's theoretical deduction. Winnecke's comparison of the Pulkova and Cape observations of Mars yields 8·964″.

Thus though there might be some uncertainty in the amount of the correction, there was no doubt that the Sun was nearer than was formerly considered to be the case.

The distance amended to accord with a parallax of 8·94″ is about 91,430,000 miles.

Hansen contributed something towards the elucidation of the matter, which must not be passed over. As far back as 1854 this distinguished mathematician expressed his belief that the received value of the solar parallax was too small, and in 1863 he communicated to Sir G. B. Airy a new evaluation, derived from his Lunar theory by the agency of the co-efficient of the parallactic inequality. The result was 8·9159″, a quantity fairly in accord with the other values set forth above[h].

[d] *Month. Not.*, vol. xvii. pp. 208–21. May, 1857. Some practical hints on the conduct of observations are given by A. Hall in *Ast. Nach.* vol. lxviii. No. 1623. Jan. 16, 1867.

[e] *Annales de l'Observatoire Impériale*, vol. iv. p. 101. Paris, 1861.

[f] *Month. Not.*, vol. xxvii. p. 241. April 1867.

[g] *Month. Not.*, vol. xxiii. p. 185. April 1863.

[h] *Month. Not.*, vol. xxiv. p. 8. Nov. 1863. The amount of the correction to Encke's determination is about equal to the apparent breadth of a human hair seen from a distance of 125 ft., or that of a sovereign at a distance of 8 miles.

Such is a brief statement of the circumstances which caused such special interest to attach to the transit of Venus which was to happen on December 8, 1874: for it was recognised, that, all things considered, transits of Venus were most to be relied on for the purpose of ascertaining the amount of the Sun's parallax. The particular circumstances of the transit in question, and the results obtained from it, will come under notice hereafter. It seems almost needless to add that the acceptance of a new value for the solar parallax necessitates the recomputation of all numerical quantities involving the Sun's distance as a unit.

The real mean distance of the Earth from the Sun being ascertained, it is not difficult to determine by trigonometry the true diameter of the latter body, its apparent diameter being known from observation[1]; and, as the most reliable results show that the Sun at mean distance subtends an angle of 32′ 3·6″, it follows that (assuming, as above, a parallax of 8·94″) its actual diameter is 852,692 miles. It is generally accepted that there is no visible compression. The surface of this enormous globe therefore exceeds that of the Earth 11,614 times, and the volume 1,251,570 times; since the surfaces of the spheres are to each other as the squares of the diameters, and the volumes as the cubes.

The lineal value of 1″ of arc at the mean distance of the Sun is 443 miles.

The Sun's mass, and consequently its attractive power, exceeds that of the Earth 314,049 times, and (approximately) is 742 times the masses of all the planets put together.

By comparing the volumes of the Sun and the Earth and bringing in the value of the masses, we obtain the relative specific gravity or density of the two.

The Sun's volume exceeds that of the Earth in the ratio of 1,251.570 to 1; the Sun's mass exceeds the Earth's in the lesser ratio of 314,049 to 1. Therefore the density of the Sun is to the density of the Earth as 314,049 to 1,251,570, or approximately as 1 to 4. Then taking Baily's value of the density of the Earth (5·67 times that of water), the density of the Sun is 1·42 times that of water.

[1] Lindenau in 1809 and Secchi in 1872 propounded some strange ideas about the visible diameter of the Sun being subject to periodical change, but those ideas have met with no favour. (Auwers in *Month. Not.*, vol. xxxiv. p. 22. Nov. 1873.)

Some interesting points may be conveniently noted here respecting the consequences which must be deemed to flow from the stupendous magnitude and mass of the Sun. At the surface of the Earth a body set free in space falls 16·1 feet in the first second of time, with a velocity increasing during each succeeding second. A body similarly set free at the surface of the Sun would start with a velocity 27·1 times as great as that of a body falling at the surface of the Earth. This is equivalent to saying that a pound weight of anything on the Earth would, if removed to the Sun, weigh more than 27 lb. Liais has pointed out a singular consequence of this fact:—"An artillery projectile would have on the Sun but very little movement. It would describe a path of great curvature, and would touch the surface of the Sun a few yards from the cannon's mouth." On the Earth the centrifugal force due to the Earth's rotation diminishes gravity in a proportion which increases from the pole to the equator. At the equator the total diminution is $\frac{1}{289}$th. At the Sun's equator the centrifugal force is only about $\frac{1}{18000}$th part of the force of gravity. It would be necessary that the Sun should turn on its axis 133 times quicker than it does, for the force of gravity to be neutralised. In the case of the Earth, however, a speed of rotation 17 times as great as it is would suffice to produce the same result. The insignificance of centrifugal force at the Sun's equator, compared with the amount of the force of gravity, suffices to explain the absence of appreciable polar compression in the case of the Sun's disc.

A consideration of the comparative lightness of matter composing the Sun led Sir J. Herschel to think that it is "highly probable that an intense heat prevails in its interior, by which its elasticity is reinforced, and rendered capable of resisting [the] almost inconceivable pressure [due to its intrinsic gravitation] without collapsing into smaller dimensions[k]." That the internal pressure exerted by the gases imprisoned by the luminous surface or photosphere of the Sun, must be absolutely stupendous, we have evidence in the fact of the almost inconceivable velocity (100 to 200 miles per *second*) of the uprushes of incandescent gas and metallic vapours, which are almost constantly taking place at various parts of its surface. It would seem all but certain that

[k] *Outlines of Ast.*, p. 297.

the Sun is nearly wholly gaseous, and that its photosphere consists of incandescent clouds, in which the aqueous vapour of our terrestrial clouds is replaced by the vapours of metals. These considerations, however, introduce a difficulty of a precisely opposite character to that which Sir J. Herschel essayed to combat; inasmuch as, in the light of our present knowledge, it seems hard to conceive how a mere shell of metallic vapour should be able to confine gases at the incomprehensible pressure at which those which rush out in the form of the now well-known "red flames" (see *post*) must be confined.

We thus see that the Sun is eminently worthy of the important position it holds as the centre of our system, and thus early it will be appropriate to mention that the Sun is to be regarded as a fixed body so far as we are concerned; when therefore we say that the Sun "rises," or the Sun "sets," or the Sun moves through the signs of the zodiac once a year, we are stating a conventional untruth; it is *we* that move and not the Sun, the apparent motion of the latter being an optical illusion.

The Sun is a sphere, and is surrounded by an extensive and rare atmosphere; it is self-luminous, emitting light and heat which are transmitted certainly beyond the planet Neptune, and therefore more than 2700 millions of miles. Of the Sun's heat, it has been calculated that only $\frac{1}{2381000000}$ part reaches us[l], so what the whole amount of it must be it passes human comprehension to conceive: like many other things in science. Our annual share would be sufficient to melt a layer of ice all over the Earth 100 feet in thickness, or heat an ocean of fresh water 60 miles deep from 32° F. to 212° F., according to Herschel and Pouillet[m]. Another calculation determines the direct light of the Sun to be equal to that of 5563 wax candles of moderate size, supposed to be placed at a distance of one foot from the observer. The light of the Moon being probably equal to that of only one candle at a distance of 12 feet, it follows, according to Wollaston, that the light of the Sun exceeds that of the Moon

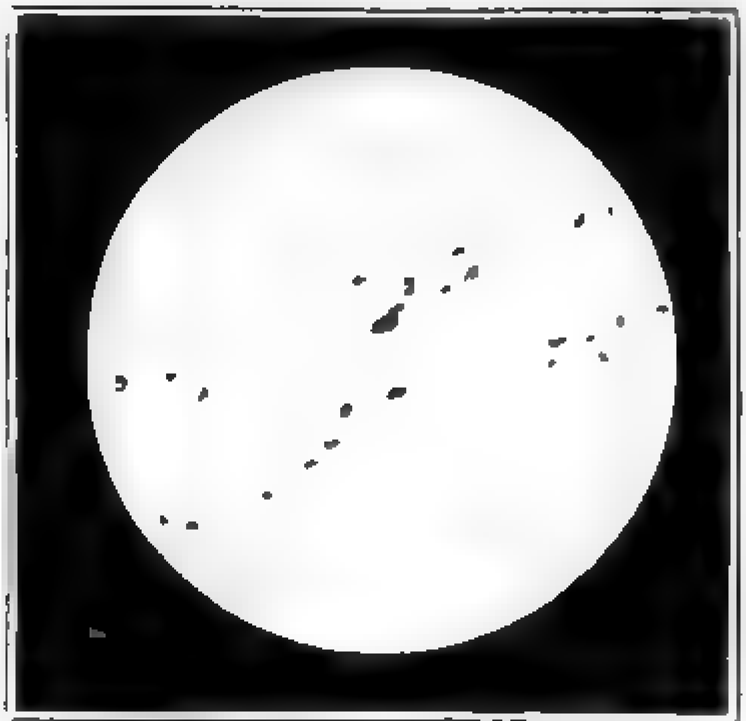
[l] Ganot, *Physics*, p. 331. Eng. ed. 1863. This was calculated on the old value of the solar parallax. I have not altered it.

[m] To show the great power of the calorific rays of the sun, I may mention that in constructing the Plymouth Breakwater, the men, working in diving bells, at a distance of 30ft below the surface, had their clothes burnt by coming under the focus of the convex lenses placed in the bell to let in the light. And houses have been set on fire by the Sun's rays.

801,072 times. Zöllner's ratio is 618,000 to 1, and Bouguer's 300,000 to 1.

When telescopically examined, there may frequently be seen in the equatorial zones of the Sun dark spots or *maculæ*[n], each surrounded by a fringe of a lighter shade, called a *penumbra*[o], the two not passing into each other by gradations of tints, but abruptly. In the few cases in which a gradual shading has been noticed, Sir J. Herschel believed that the circumstance may be ascribed to an optical illusion, arising from imperfect definition on the retina of the observer's eye. It is not however always the case that each spot has a penumbra to itself, several spots being occasionally included in one penumbra. And it may further be remarked that cases of an umbra without a penumbra, and the contrary, are on record, though these may be termed exceptional, and considered as closely relating to material physical changes just commencing or terminating. A marked contrast subsists in all cases between the luminosity of the penumbra and that of the general surface of the Sun contiguous. Towards their exterior edge the penumbræ are usually darker than nearer the centre. Penumbræ are usually

Fig. 2.



GENERAL TELESCOPIC APPEARANCE OF THE SUN.

[n] Lat. *macula*, a blemish. Dawes upheld a further classification: he applied to the ordinary black central portions the term *umbra* (shadow), on the highly probable ground that the blackness is mainly relative. Patches of deeper blackness are occasionally noticed in the umbræ; Dawes limited to these the designation *nucleus*, sometimes indiscriminately applied to all the blackish area. This classification is adopted in the text. Mr. Langley of the Allegheny observatory however, viewing spots with the 13 inch Equatorial of that institution, and a polarizing eye-piece (which admits of the employment of the whole aperture), sees that the umbral structure is quite complex, and made up of sunken banks of "filaments" (see *post*). He further perceives that the nucleus which Dawes speaks of as "intensely black," is not black at all, nor even dark (save relatively), but is brilliant with a violet-purple light. (*Month. Not.*, vol. xxxiv. p. 259. March 1874.)

[o] *Pene* almost, and *umbra* a shadow.

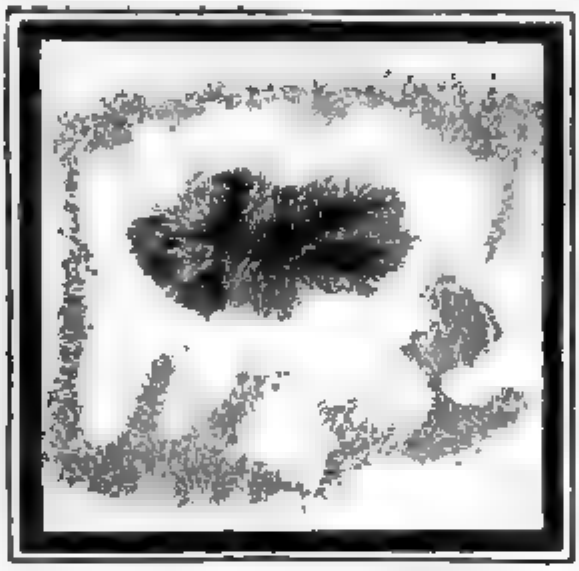
very irregular in their outlines, but the umbræ, especially in the larger spots, are often of regular form (comparatively speaking, of course), and the nuclei of the umbræ still more noticeably possess a compactness of outline.

Spots are for the most part confined to a zone extending 35° or so on each side of the solar equator, and are neither permanent in their form nor stationary in their position, frequently appearing and disappearing with great suddenness.

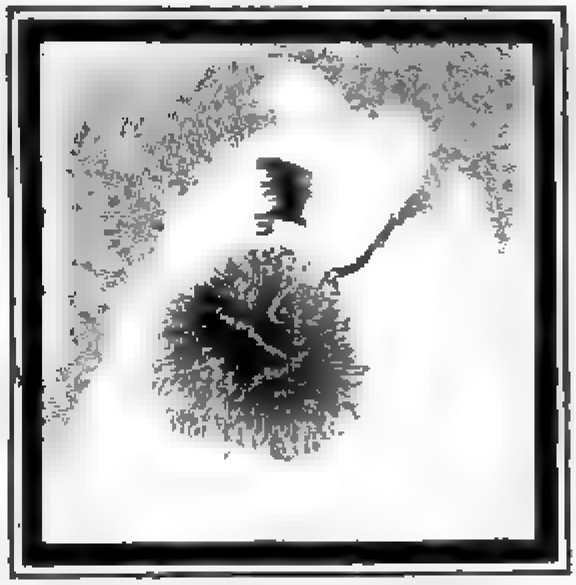
The multitude of facts concerning them, accumulated from the journals of many observers extending over long periods of years, is so great as to bewilder one, and to marshal these in a suitable manner is a task of extreme difficulty: and howsoever performed it is certain that much will have been left out that might with advantage have been inserted.

The general limits in latitude of the spots may be stated, as above, at 35°, but instances of spots seen beyond these limits are on record. In 1871, B. Stewart saw one 43° distant from the solar equator; in 1858, Carrington one 44° 53′; in 1826, Capocci one 46°; in 1846, C. H. Peters one 50° 55′; and La Hire, in the last century, is said to have seen one in latitude 70°. They are confined to two belts on either side of the Sun's equator, being rarely if ever seen directly under the equator, or nearer to it than 8° of north or south latitude: from 8° to 20° is their most frequent range. They are always more numerous and of a greater general size in the northern hemisphere; the zone between 11° and 15° north is particularly noted for large and enduring spots. A gregarious tendency is very obvious, and where the groups are very straggling, the longer line joining extreme ends will pretty generally be found to be more or less parallel to the equator, and not only so, but extending across nearly the whole of the visible disc.

Sir John Herschel remarks:—"These circumstances .... point evidently to physical peculiarities in certain parts of the Sun's body more favourable than in others to the production of the spots, on the one hand; and on the other, to a general influence of its rotation on its axis, as a determining cause in their distribution and arrangement, and would appear indicative of a system of movements in the fluids which constitute its luminous surface; bearing no remote analogy to our trade-winds—from whatever



1826 : July 2. (*Capocci.*)



1826 . September 29. (*Capocci.*)

1861 : May 23. (*Birt.*)

1861 : May 27. (*Anon.*)

SPOTS ON THE SUN.

cause arising[p]." In reference to the distribution *in latitude* of the spots, the observations of Carrington have placed us in possession of some important facts. That observer found that as the epoch of minimum approached, the spots manifested a very distinct tendency to advance towards the equatorial regions, deserting to a great extent their previous haunts above the parallels of 20° or so. After the minimum epoch had passed, a sudden and marked change set in, the equatorial regions becoming almost deserted by the spots, which on their reappearance showed themselves chiefly in parallels higher than 20°. Wolf finds that the observations of Böhm reveal the fact that the same peculiarity was noticed by that observer in the years 1833–6[q]. Whether this is a general rule remains yet to be ascertained, but Sir John Herschel remarks that if such be the case, "it cannot but stand in immediate and most important connexion with the periodicity itself, as well as with the physical process in which the spots originate."

The duration of individual spots is a matter associated with extremes both ways. Some remain visible for several months, others scarcely for as many minutes; but a few days or weeks will commonly be found the usual extent of permanency. Some are formed and vanish during the period of a single transit (rather more than $12\frac{1}{2}^{d}$), others remain during several successive transits; for it will be readily understood that the Sun, being endued with an axial rotation, and the spots being fixed (or nearly so) on the Sun's surface, it will not be possible for any one spot to remain in sight *continuously* for longer than the semi-duration of the Sun's rotation.

With respect to the distribution of spots as regards *longitude* there is little to be said, for it does not certainly appear that they have a preference for any one longitude more than another. Nevertheless Kirkwood believes that this statement needs modification to this extent: that there is one particular longitude on which planetary influences (see *post*) are specially effective.

When observed for any length of time, a spot will first be noticed on the Eastern limb, disappearing in little less than a

[p] *Outlines of Ast.*, p. 251.
[q] *Month. Not.*, vol. xix. p. 325. July 1859.

fortnight on the Western limb; after an interval of nearly another fortnight, the spot, if still in existence, will reappear on the Eastern side, and in like manner traverse the disc as before. This phenomenon necessarily can only be accounted for on the supposition that the Sun rotates on its axis; and observations specially conducted with that object in view will give the period of this rotation, which Laugier fixed at $25^d\ 8^h\ 10^m$; Carrington at $25^d\ 9^h\ 7^m$; and Spörer at $25^d\ 5^h\ 31^m$—results fairly in accord with Bianchini's determination of $25^d\ 7^h\ 48^m$, deduced in 1718, when the difficulties attending the observations due to the ever-varying forms and actual proper motions of the spots are taken into consideration.

The entire period required by a spot to make a whole visual rotation ($27^d\ 7^h$) is greater than that of the Sun's actual rotation, owing to the Earth's progressive movement in its orbit.

On February 19, 1800, Sir W. Herschel states that he was watching a group, but that on looking away for a single moment, it could not be found again[r]. The same observer followed a spot, in 1779, for six months; and, in 1840 and 1841, Schwabe observed one and the same group to return eighteen times, though not consecutively[s]. In July, August, and September 1859, a large group was followed through several apparitions, and another very noticeable instance of the kind occurred in the autumn of 1865. Similar cases are by no means very rare. It has been surmised, and Sir J. Herschel thought "with considerable apparent probability," that some spots at least are generated again and again, at distant intervals of time, over the same identical points of the Sun's body. There does not appear to be much evidence to bear out this hypothesis[t], and the fact now recognised, that proper motion exists with some of them, is of course directly at variance with it. The Rev. T. W. Webb says:—"Fritsch stated that he saw one stand nearly still for three days; and Lowe that he even witnessed retrogradation—but these assertions involve a suspicion of mistake. Schröter and others have ascribed to them a more moderate locomotion. This was micrometically established

[r] *Phil. Trans.*, vol. xci. p. 293. 1801.

[s] *Ast. Nach.*, vol. xviii. No. 418. March 18, 1841.

[t] Sir John seems afterwards to have changed his opinion. In a Memoir in the *Quart. Jour. Sc.*, vol. i. p. 226, April 1864, he says exactly the reverse.

in a lateral direction by Challis in 1857; and Carrington has subsequently made known his very interesting discovery, that there appear to be currents in the photosphere, drifting the equatorial spots forward in comparison with those nearer to the poles, with deviations in latitude of smaller amount: the neutral line as to both these drifts lying in about 15° of latitude. With these shifting landmarks, it is not surprising that the Sun's period of rotation is still doubtful. Laugier's value, $25^d\ 8^h\ 10^m$, was formerly adopted, but Carrington has given $24^d\ 23^h\ 18^m\ 23^s$, Spörer $24^h\ 14^m\ 59^s$. Perhaps, as Carrington suggests, the interior mass may revolve with greater speed. Relative displacement in groups would be an interesting study, requiring neither micrometer nor clock, only careful drawing. . . . Howlett and several others have found that spots near the limb require a different focus from those in the centre; arising, no doubt, as Dawes says, from the effect on the retina of very different degrees of brightness[u]."

With respect to proper motion, Carrington found that most spots have an independent proper motion of their own (hence uncertainties in conclusions respecting the duration of the Sun's rotation), and not only so, but that the proper motions of spots vary systematically with the latitudes of the spots.

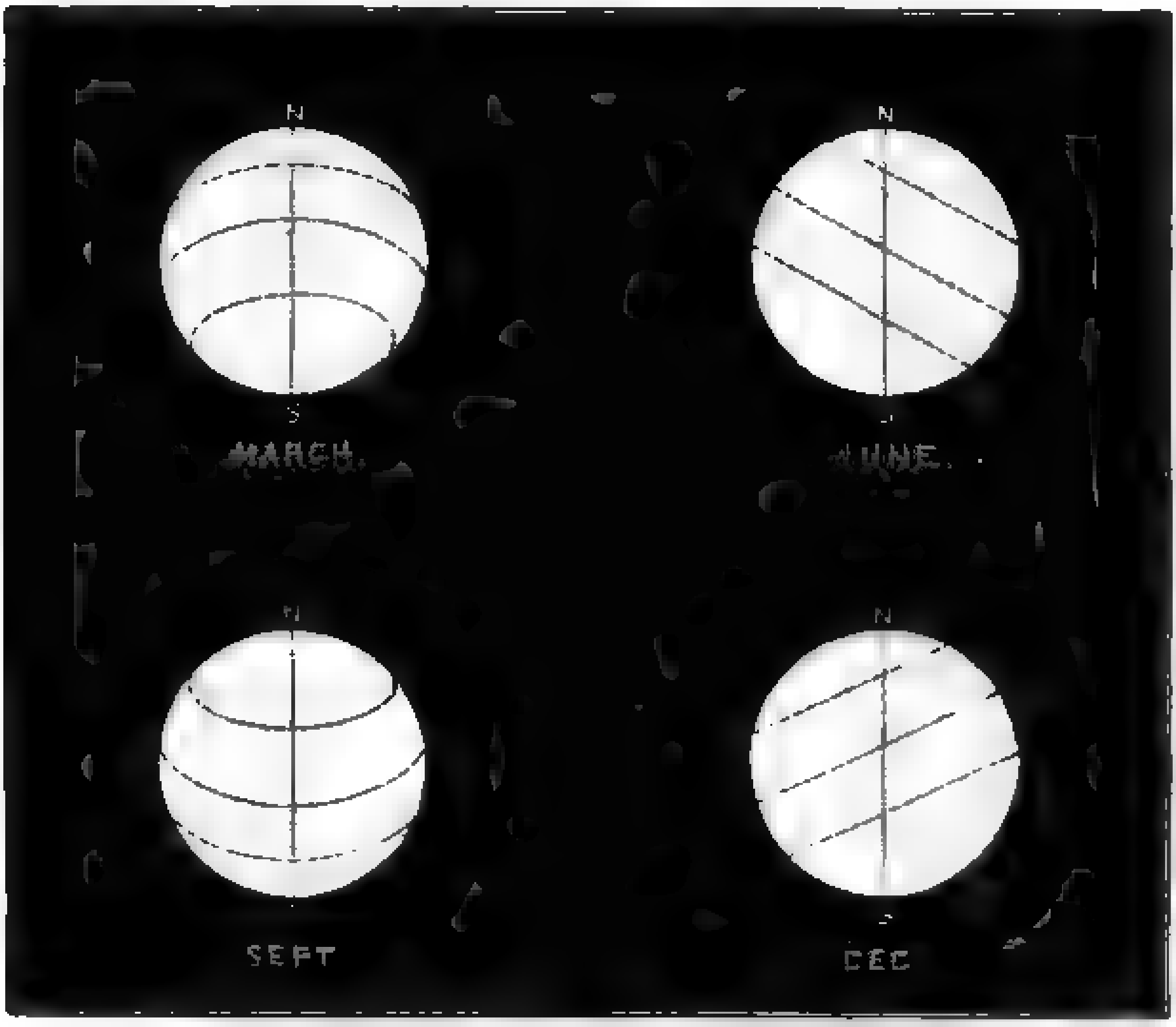
The varying position of the Earth with reference to the Sun, combined with the inclination of the axis of the latter to the plane of the ecliptic (amounting to 82° 45′ according to Carrington; to 83° 3′ according to Spörer[x]), gives rise to the fact that at no two periods of the year do the spots *appear* to traverse the Sun's disc exactly in the same way. About June 5 and December 6 the Earth is in the line of nodes of the spots—or, in other words, its longitude, as seen from the Sun, corresponds nearly with the points of intersection of the solar equator and the ecliptic—and the paths of the spots are then inclined straight lines. In March the South pole is turned towards us, and the tracks are concave towards the South; in September the conditions are precisely reversed in every respect, the North pole is turned towards us and the tracks are concave towards the North; at other intermediate periods (not being very near to June 5 or

[u] *Celest. Objects*, p. 33. (3rd ed.)

[x] The longitude of the ascending node for 1850 was 73° 40′; so that the North pole of the Sun's axis points nearly to π Draconis, and the South one to α Trianguli Australis.

December 6) the paths are both inclined and curved at the same time.

Fig. 7.



PATHS OF SUN SPOTS AT DIFFERENT TIMES OF THE YEAR.

If we represent the luminous surface of the Sun, when the Earth is at its mean distance, by 1000, the numbers 967 and 1035 will represent the same surface as it appears to us when the Earth is in Aphelion (July) and in Perihelion (January) respectively.

Individual spots also possess many personal peculiarities. Dawes observed one on January 17, 1852, which, by the 23rd of that month, had rotated in its own plane through 90°. Birt believes the same thing happened with a spot which he scrutinised in February and March 1859[y]. Schwabe has seen occasionally spots of a reddish-brown colour, under circumstances of contrast precluding the possibility of deception; on one occasion three telescopes and several bystanders certified to this. In 1826, Capocci perceived a violet haze issuing from each side of the bright central

[y] *Month. Not.*, vol. xix. p. 182. March 1859.

streak of a great double umbra; and during the eclipse of March 15, 1858, Secchi saw a rose-coloured promontory in a spot visible to the naked eye. Schwabe describes the penumbræ as made up of a multitude of black dots, usually radiating in straight lines from the umbra; Secchi, with greater optical power, defines these radiations to be alternate streaks of the bright light of the photosphere and dark veins converging to the umbra[z].

Some of these spots are of prodigious size, and are therefore visible to the naked eye. A few recent instances are here given. A spot measured by Pastorff on May 24, 1828, was computed to have an area about four times the entire surface of the Earth. In June 1843, Schwabe observed one 2′ 47″, or 75,000 miles in diameter. It was seen for an entire week without the aid of a telescope. On March 15, 1858, the day of the celebrated eclipse, a spot having a breadth from west to east of 4′, or 106,000 miles, attracted considerable attention. On September 30, in the same year, one having a breadth from west to east of 5′ 21″, or 142,000 miles, was observed[a]. On January 26, 1859, and during August 1859, large spots were seen; one visible in the latter month measured nearly 58,000 miles, according to Newall, who saw it distinctly as a notch on the edge of the Sun's disc, the like of which he had only seen once before—namely, on March 25, 1850[b]. During April and May 1870 several large spots, easy to be seen by the naked eye, were visible. One of the most interesting large spots ever subjected to careful scrutiny was that which was conspicuously visible in October 1865. Many elaborate observations of it were made by astronomers, and a series of drawings by the Rev. F. Howlett are well known. I here present drawings by Mr. F. Brodie, exhibited at the Royal Astronomical Society[c] but not hitherto published, and which will be useful for comparison with Mr. Howlett's. He has furnished me with the following revised transcript of his notes:—

[z] The preceding facts are given on the authority of Webb, *Celest. Objects*, p. 25. He gives no references, so I am unable to verify them.

[a] *Ast. Nach.*, vol. l. No. 1182. Feb. 25, 1859.

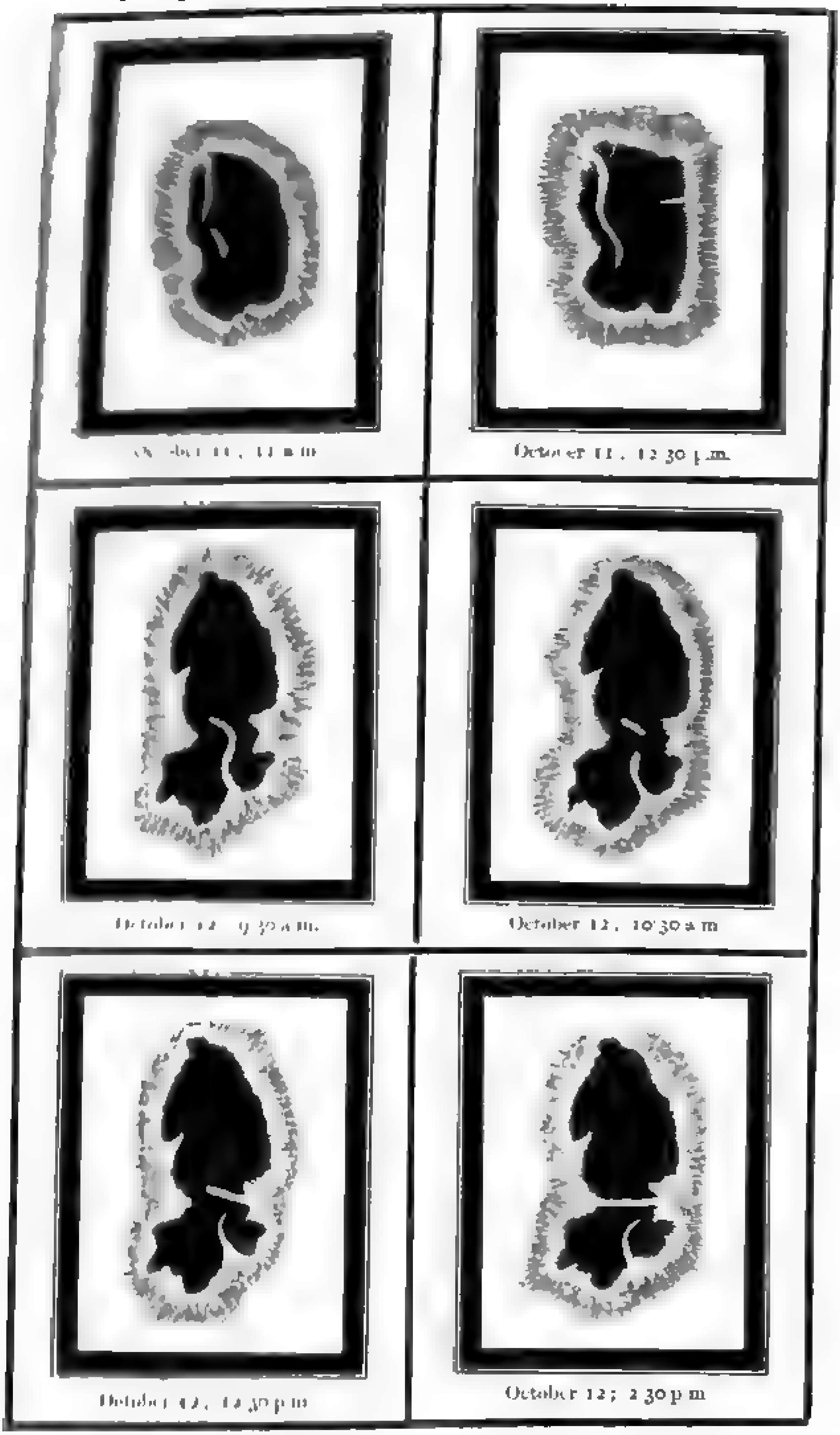
[b] Letter in the *Times*, Aug. 27, 1859. "An indentation on a globe will disappear in profile unless its breadth and depth are considerable: hence such observations would be rare, but they are recorded by La Hire, 1703; Cassini, 1719; W. Herschel, 1800; Dollond and others, 1846; Lowe, 1849; Newall, 1850, 1859; Observers at Kew and Dessau, 1868."—Webb, *Celest. Objects*, p. 28 (n.).

[c] *Month. Not.*, vol. xxvi. p. 21. Nov. 1865.

"OCTOBER 11, 1865.—The definition was fine enough to allow this spot to be examined with a power of 470 on an equatorial telescope of 8½ in. aperture and 11½ ft. long. The shape of the spot was tolerably rectangular, the umbra being about 18,000 miles long and 9700 miles wide, or in measures of arc 41·3″ long and 22·3″ wide. The penumbra 86·9″ long and 73·5″ wide. There was an exceedingly long promontory of luminous matter projecting over the umbra from one end of the spot, and running tolerably parallel to the side. Near the end of this promontory was an elongated portion of detached luminous matter of similar shape to that of the promontory itself, about 4000 miles long [see Plate III. Fig. 8]. This portion had elongated itself in a remarkable manner in the previous 15 minutes, for when first observed it was not more than about 3000 miles long. The long promontory seemed drifting towards the penumbra, while the detached portion was moving rather away from it, indicating a cyclonic action of the forces in operation.

"About 1½ hours later I found that the detached portion of luminous matter had formed a junction with the long promontory [see Plate III. Fig. 9]. That side of the umbra opposite to this promontory was covered with a sort of 'mackerel sky' formation of misty luminous matter, which extended more or less marked over the whole portion of the umbra. The *black* nucleus of the umbra first noticed by Mr. W. R. Dawes, as generally to be seen in spots, was absent in this umbra. This misty cloud-like appearance of the umbra can only be seen with large telescopes; it seems to be formed by the nodules of luminous matter that break off from the pectinations which fringe the whole of the edge of the umbra; these soon after become more and more diffused, until they become a sort of cloudy stratum floating over the umbra. These nodules invariably drift from the edge of the penumbra towards the centre of the umbra, which would seem to indicate a downward rush of gases from the surface of the sun. On October 12th there were five of these nodules, that had broken off from the ends of the small promontories or pectinations at the edge of the penumbra and had begun to drift on to the umbra, while one had not quite broken away, but was preparing to do so [see Fig. 14]. There was now also another change on the umbra at the end of the long promontory; the misty cloud-like masses of luminous matter began to form into bridge-like formations [see Plate III. Fig. 9]; but these formations were not nearly so bright and defined as the long portion of the promontory: there was also another shorter promontory formed on the opposite side to that of the long one, or it might be termed an extreme lengthening of one of the pectinations. The rapidity of change in all parts of the umbra was remarkable, the cloudy strata seeming to condense and diffuse very similar to our earth clouds on a summer's day.

"OCTOBER 12.—The shape of the umbra was very greatly altered, and its size was much increased [see Plate III. Fig. 10]. Its length was nearly 29,000 miles, with a width in the greatest part of 10,400 miles, or 65·2″ of arc long, and 23·6″ wide, the penumbra being 50,000 miles long and 34,000 broad. The long promontory of yesterday had quite disappeared, and there was another formed at the opposite end of the spot of a serpentine form; this was observed at 9·30 A.M. Within an hour another change took place, and at 10·30 this long serpentine promontory had broken into two portions, the shorter end floating on the penumbra [see Fig. 11]. At 12·30 P.M. the one end of that portion that had broken off had bodily floated towards the penumbra and formed a junction, as seen in Fig. 12. At 2·30 P.M. the spot was again observed, and the portion originally broken off from the serpentine promontory of the morning had formed a complete bridge across the umbra [see Fig. 13], while the part from which it was broken had bent round, forming nearly a semicircle. The



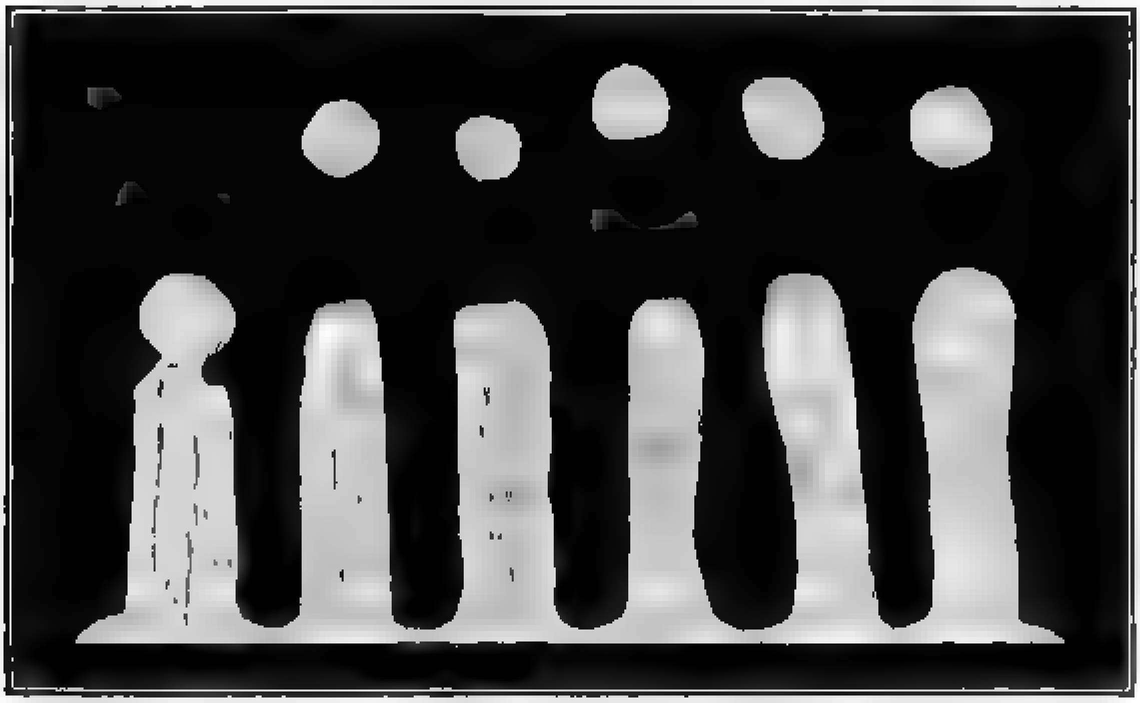
THE GREAT SUN-SPOT OF OCTOBER 1865.

(Drawn by Brodie.)

outline of the spot did not seem to change perceptibly. The figure of the spot was thrown by the telescope on to a board and sketched from its own image.

"OCTOBER 13.—The shape of the spot slightly altered only, but the bridge across had quite disappeared, while the semicircular promontory had formed a junction with the penumbra."

Fig. 14.



THE GREAT SUN-SPOT OF OCTOBER 1865. PECTINATED EDGE VISIBLE ON OCTOBER 12. (*Brodie.*)

Schwabe says that good eyes will detect without optical aid any spots more than 50″ in diameter, but this is doubtful. Probably the minimum limit must be fixed in general at 1′.

"The origin of a spot, when it can be observed, is usually traceable to some of those minute *pores* or dots which *stipple* the Sun's surface, and which begin to increase, to assume an *umbral* blackness, and acquire a visible and, at first, very irregular and changeable shape. It is not till it has attained some measurable size that a penumbra begins to be formed—a circumstance strongly favouring the origination of the spot in a disturbance from below, upward; *vice versâ*, as the spots decay they become bridged across, the umbræ divide, diminish in size, and close up, leaving the penumbræ, which, by degrees, also contract and disappear. The evanescence of a spot is usually more gradual than its formation. According to Professor Peters and Mr. Carrington, neighbouring groups of spots show a tendency to recede from one another[d]."

The most indifferent observer can hardly fail to be struck with

[d] Sir J. Herschel, in *Quart. Journ. Sc.*, vol. i. p. 225. April 1864.

the rapidity of the changes which take place in solar spots. Dr. Wollaston says:—"Once I saw, with a 12-inch reflector, a spot burst to pieces while I was looking at it. I could not expect such an event, and therefore cannot be certain of the exact particulars; but the appearance, as it struck me at the time, was like that of a piece of ice when dashed on a frozen pond, which breaks in pieces, and slides on the surface in various directions. I was then a very young astronomer, but I think I may be sure of the fact." Their immense number is likewise very noticeable. On April 26, 1846, Schmidt of Bonn counted upwards of 200 single spots and points in one of the large groups then visible, and 180 in another cluster, in August 1845. On August 23, 1861, I counted 70 distinct spots with a telescope of only 3 inches' aperture charged with a power of 21. Schwabe finds that the Western members of a group disappear first, and that at the Eastern end fresh ones are apt to form, where also the junior members are most numerous; that the small points are usually arranged in pairs (much after the appearance of the "dumb-bell" nebula); and that, when near the edge of the Sun, the penumbræ are much brighter on the side next the limb. Sir J. Herschel has often noted the penumbræ to be least defined on the preceding side; and Capocci found the principal spot of a group usually the leader. The same observer believed the umbræ to be better defined in their increase than in their decrease. The leader is usually the most black, symmetrical, and enduring of the group, according to Chacornac.

Attention has now to be directed to one of the most curious and interesting discoveries of modern astronomy—the periodicity of the solar spots. Schwabe, of Dessau, the hero of this, shall be introduced to the reader in the words of the late Mr. M. J. Johnson, when, as President of the Royal Astronomical Society, he spoke on the award to him of the Society's Gold Medal in 1857:—

"What the Council wish most emphatically to express is their admiration of the indomitable zeal and untiring energy which he has displayed in bringing that research to a successful issue. Twelve years, as I have said, he spent to satisfy himself; six more years to satisfy, and still thirteen more to convince, mankind. For thirty years never has the Sun exhibited his disc above the horizon of Dessau without being confronted by Schwabe's imperturbable telescope, and that appears to have happened, on an average, about 300 days a year. So, supposing that he observed but once a day, he has made 9000 observations, in the course of which he discovered

4700 groups. This is, I believe, an instance of devoted persistence (if the word were not equivocal, I should say pertinacity) unsurpassed in the annals of astronomy. The energy of one man has revealed a phenomenon that had eluded even the suspicion of astronomers for 200 years[e]."

TABLE OF SCHWABE'S RESULTS[f].

Year.	Days of Observation.	Days of no Spots.	New Groups.	Mean diurnal Variation in Declination of the Magnetic Needle.
				"
1826	277	22	118	9·75
1827	273	2	161	11·33
1828	282	0	225	11·38
1829	244	0	199	14·74
1830	217	1	190	12·13
1831	239	3	149	12·22
1832	270	49	84	..
1833	247	139	33	..
1834	273	120	51	..
1835	244	18	173	9·57
1836	200	0	272	12·34
1837	168	0	333	12·27
1838	202	0	282	12·74
1839	205	0	162	11·03
1840	263	3	152	9·91
1841	283	15	102	7·82
1842	307	64	68	7·08
1843	312	149	34	7·15
1844	321	111	52	6.61
1845	332	29	114	8.13
1846	314	1	157	8.81
1847	276	0	257	9·55
1848	278	0	330	11·15
1849	285	0	238	10.64
1850	308	2	186	10·44
1851	308	0	151	8.32
1852	337	2	125	8.09
1853	299	3	91	7·09
1854	334	65	67	6.81
1855	313	146	79	6·41
1856	321	193	34	5·98
1857	324	52	98	6·95
1858	335	0	188	7·41
1859	343	0	205	10·37
1860	332	0	211	10.05
1861	322	0	204	9·17
1862	317	3	160	8·59
1863	330	2	124	8.84
1864	325	4	130	8.02
1865	307	25	93	8·14
1866	349	76	45	7·65
1867	312	195	25	7·09
1868	301	23	101	8·15

[e] *Month. Not.*, vol. xvii. p. 129. Feb. 1857.

[f] *Month. Not.*, vol. xvi. p. 63. Jan. 1856. Continued to 1868.

Schwabe's observations, as published, end with 1868. The thread is not however absolutely broken, for Wolf had previously started a series of his own, a table of which, as prepared by himself for this work, at my request, is subjoined:—

Year.	Days of Observation.	Days of no Spots.	Relative Number.	Mean diurnal variation in Magnetic Declination at Prague.	
				Observed.	Calculated.
1849	313	0	95·9	10·27	10·21
1850	325	7	66·6	9·97	8·88
1851	311	0	64·5	8·32	8·79
1852	322	4	54·2	8·09	8·33
1853	332	6	39·0	7·09	7·64
1854	348	67	20·6	6·81	6·82
1855	352	223	6·7	6·41	6·19
1856	356	256	4 3	5·98	6·08
1857	363	70	22·8	6·95	6·92
1858	335	2	54·8	7·41	8·36
1859	334	0	93·8	10·37	10·11
1860	363	0	95·7	10·05	10·20
1861	364	2	77·2	9·17	9·36
1862	359	4	59·1	8·59	8·55
1863	361	2	44·0	8·84	7·87
1864	352	7	46·9	8·02	8·00
1865	361	42	30·5	7·80	7·26
1866	363	85	16·3	6·63	6·62
1867	360	219	7·3	6·47	6·22
1868	351	37	37·3	7·27	7·57
1869	341	2	73·9	9·44	9·22
1870	354	0	139·1	11 47	12·15
1871	363	0	111·2	11·60	10·89
1872	365	0	101·7	10·70	10·47
1873	363	14	66·3	9·05	8·87
1874	363	12	44·6	7·98	7·90

The gist of this discovery may be given in a few words:—the spots are subject to a periodical variation in prevalence, to the amount of about 10$^{\text{years}}$; during this time their numbers follow a cycle which has a maximum and a minimum. At epochs of minima, on many days absolutely no spots are to be seen, as was the case in 1856. It has been hinted that at epochs of maxima, spots are more permanent in character, that is, can be more often watched through several rotations than is the case at epochs of minima; but the idea needs confirmation.

A remarkable discovery has grown out of Schwabe's; namely, that the diurnal variation in the declination of the magnetic needle is characterised by a 10-$^{\text{year}}$ period, and (this is the singular

circumstance) that the epoch of maximum variation corresponds with the epoch of the maximum prevalence of sun-spots, and *vice versâ*, minimum with minimum. Lamont of Munich announced, about 1850, the fact of the period, and General Sabine, in March 1852[g], the fact of the coincidence; Gautier and Wolf making the same deduction independently of Sabine and of each other.

Two other curious discoveries have made been in close connection with the foregoing, and it is now accepted that auroræ and magnetic earth currents (currents of electricity which frequently travel below the surface of our globe, and interfere with telegraphic operations) likewise have a 10-year period, and that their maxima and minima are contemporaneous with those of the two phenomena dealt with above; "so that," in the words of Balfour Stewart, "a bond of union exists between these four phenomena. The question next arises, What is the nature of this bond? Now, with respect to that which connects Sun-spots with magnetic disturbances, we can as yet form no conjecture; but we may, perhaps, venture an opinion regarding the nature of that which connects together magnetic disturbances, auroræ, and earth-currents[h]." The reality of the coincidences just adverted to will be best understood by an examination of the accompanying engraving of curves, which I copy from Loomis, who has investigated with great care the historical evidence available for drawing trustworthy conclusions in respect of these matters. Loomis points out that the discrepancies in the coincidences of critical periods in the three phenomena of Sun-spots, magnetic declination, and auroræ are both few and insignificant. His memoir will well repay attentive perusal[i].

Much more might be said on these matters, but a fuller elucidation of them would lead us into non-astronomical fields.

I may here advert to a remarkable phenomenon seen on September 1, 1859, by two English observers whilst engaged in scrutinising the Sun. A very fine group of spots was visible at the time, and suddenly, at $11^{h}\ 18^{m}$ a.m., two patches of intensely bright white light were seen to break out in front of the spots. They were at first thought to be due to a fracture of the

[g] *Phil. Trans.*, vol. cxlii. p. 103. 1852.
[h] *Proceedings of the Royal Inst.*, vol. iv. p. 58. 1863.
[i] *Silliman's Journal*, vol. v. (3rd s.) p. 245. April 1873; vol. 50. (2nd s.) p. 153. Sept. 1870.

screen attached to the object-glass of the telescope, but such was not the case. The patches of light were evidently connected with the Sun itself; they remained visible for about 5^m, during which time they traversed a space of about 33,700 miles. The brilliancy of the light was dazzling in the extreme; but the most noteworthy circumstance was the marked disturbance which (as was afterwards found) took place in the magnetic instruments at the Kew Observatory simultaneously with the appearance in question, followed in about 16^h by a great magnetic storm [k], during which telegraphic communication was impeded, some telegraph offices were set on fire, and auroræ appeared. A storm on the Sun not altogether unlike this, it would seem, was observed on September 7, 1871, in America by Professor C. A. Young. A prominence (or uprush of gas) which he was examining with a spectroscope suddenly burst into fragments with great violence. He calculated that the velocity of ascent was as much as 166 miles per second. A portion of the fragments of matter reached 200,000 miles from the Sun's surface [l]. An aurora occurred in the evening.

Wolf has tabulated all the observations of spots which he could collect. These date from 1611, but do not assume reasonable regularity till 1749. His deductions are in accord with Schwabe's, except that he prefers a period of $11{\cdot}11^{years}$, and he considers himself warranted in asserting this law:—"Greater activity in the Sun goes with shorter periods, and less with longer periods;" and further, that there are grounds for the opinion that solar spots and variable stars are due to similar agencies.

Generally speaking, there appears a tendency with maxima to anticipate the middle time between the consecutive minima, the interval $11{\cdot}11^y$ being divided into two unequal sub-intervals of $4{\cdot}77^y$ and $6{\cdot}34^y$, or, as Sir John Herschel puts it, the maximum appears to fall about the 5th year of the period comprised between 2 minima [m]. Observations of various kinds discussed by De La Rue, Stewart, and Löwy confirm this inequality of interval, but make the sub-intervals $3{\cdot}7^y$ and $7{\cdot}4^y$, or 1 to 2. As respects the law of increase and decrease in given spot-periods their conclusion

[k] Carrington and Hodgson, *Month. Not.*, vol. xx. pp. 13-16. Nov. 1859. See also an account of a similar phenomenon noted by Brodie, in vol. xxv. p. 21. November, 1864.

[l] *Nature*, vol. iv. p. 488. Oct. 19, 1871.

[m] *Outlines of Ast.*, p. 253.

differs in an important respect from that of Professor Wolf. He appears to consider that when the spot frequency has descended rapidly or slowly from a maximum value to the next minimum, it ascends with corresponding (relative) rapidity or slowness to the next maximum. De La Rue and his associates prefer to put it that when the spot frequency has passed rapidly or slowly from a minimum to the next maximum, it descends with corresponding (relative) rapidity or slowness to the next minimum [n].

Besides the $11 \cdot 11^y$-period Wolf finds another period five times as long, and a third period three times the length of the second; in other words, that the activity of the Sun goes through a further series of changes every $55\frac{1}{2}^y$ and 166^y. He fancies that in adjacent or nearly adjacent 11^y-periods of unequal length, a greater activity during the shorter tends to compensate, in the total number of spots produced, for a less energy in the longer. The earlier observations are necessarily very imperfect [o].

The $11 \cdot 11^y$-period is now considered preferable to the 10^y one; even Schwabe assents to it, and Hansteen has, in Challis's opinion, established it for the magnetic declination.

The examination by Fritsch of a numerous assemblage of auroral observations enabled him to extend to them also the 56^y-period, as preferable to the 65^y-period proposed by Olmsted without any reference to the solar spots.

Another supposed coincidence has now to be adverted to. By carefully examining Schwabe's observations, Wolf thinks that he has detected the existence of minor periods of spot-prevalence, depending in some way on the Earth, Venus, Jupiter, and Saturn [p]. "Thus he finds a perceptibly greater degree of apparent activity to prevail *annually* on the average of months of September to January than in the other months of the year; and again, by projecting all the results in a continuous curve, he finds in it a series of small undulations succeeding each other at an average interval of 7·65 months, or $0 \cdot 637^y$. Now the periodic time of Venus (255^d) reduced to the fraction of the year is 0·616, a coincidence certainly near enough to warrant some considerable suspicion of a physical

[n] *Month. Not.*, vol. xxxii. p. 177. Feb. 1872.

[o] *Mem. Soc. Phil. de Berne.* 1852. The Table for 1749-1860 is given in *Month. Not.*, vol. xxi. p. 77. Jan. 1861.

[p] *Month. Not.*, vol. xix. p. 86. Jan. 1859.

connexion[q]." It is proper to state that Wolf does not appear to have made any use of Schwabe's observations taken subsequent to 1848[r].

B. Stewart concurs in the opinion that Planetary influences on the Sun can be traced, and he thinks that Jupiter and Mercury, as well as Venus, are concerned. The general result as to Venus is that spots have a tendency to break out at that portion of the Sun which is nearest to Venus. "As the Sun rotates carrying the newly-born spot farther away from this planet, the spot grows larger, attaining its maximum at the point farthest from Venus, and decreasing again on its approaching this planet."

Doubts must be deemed to attach to the influence assigned to Jupiter and Saturn. As Jupiter's period ($11 \cdot 8^y$) is nearly identical with the Sun-spot period, it has even been suggested that the prevalence of Sun-spots depends *mainly* on influence exerted by Jupiter in different parts of its orbit, in perihelion or aphelion, as the case may be, but the notion seems open to question for several reasons.

Schwabe is disposed to find a connection between Sun-spots and meteoric showers. There is something of a coincidence between three Sun-spot periods and one shower period, but it is probably accidental[s].

Sir W. Herschel, considering that the prevalence of numerous spots on the Sun's disc was an indication that probably violent chemical action (with the extrication of an unusual amount of light and heat) was going on, was led to think that years of abundant spots would also be noted for high temperatures and good harvests, and years of few spots for low temperatures and bad harvests[t]. Wolf, from an examination of the chronicles of Zurich from 1000 to 1800 A.D., finds decisive evidence "that years rich in solar spots are in general drier and more fruitful than those of an opposite character, while the latter are wetter and stormier than the former[u]." Gautier, from a discussion of 62 sets of observations, extending over 11^y, and taken at various places in Europe and America, has arrived at exactly the opposite conclusion[x]. A note

[q] Sir J. Herschel, *Quart. Journ. Sc.*, vol. i. p. 228. April 1864.
[r] *Mittheilungen*, No. 19.
[s] *Month. Not.*, vol. xxvii. p. 286. June 1867.
[t] *Phil. Trans.*, vol. xci. p. 316. 1801.
[u] *Mittheilungen*, No. 10.
[x] *Bibl. Univ. de Genève*, vol. li. p. 56. 1844.

of Arago's is highly appropriate here: "In these matters we must be careful not to generalise until we have amassed a large number of observations."

The general question of the influence of the Sun on the meteorology of the Earth is a large and complex one, and it has therefore received very little attention. I propose now to state what is at present known on this subject, though this will scarcely serve any more definite purpose than that of awakening a desire for further inquiry.

Some relationship certainly seems to subsist between solar spots and terrestrial cloudiness and rainfall. Baxendell considers that diversities of solar activity are to be regarded as causing changes in the magnetic condition of the Earth, and so producing changes in the directions and velocities of the great currents of the atmosphere and in the distribution of barometric pressure, temperature, and rainfall. "The future progress of meteorology must depend to a much greater extent than has been generally supposed, upon the knowledge we may obtain of the nature and extent of the changes which are constantly taking place on the surface of the sun [y]."

M. Pöey, from an elaborate catalogue of tropical storms, going back as far as 1750, finds evidence of 12 cycles of storms indicated by 12 epochs of frequent and severe storms: 10 of these epochs of maximum atmospheric disturbance corresponded to maxima of Sun spots. With respect to epochs of minima the coincidences are less noticeable; for in 11 storm minima only 5 coincidences with Sun-spot minima are to be traced. M. Pöey notes that years marked by storm maxima generally follow by one or two years the years of Sun-spot maxima [z].

A Canadian observer, Mr. A. Elvins, affirms that years in which maxima and minima of Sun-spots occur, are distinguished by general cloudiness, intermediate years being apparently much more free from clouds. He further states that records of the height of the water in Lake Ontario kept for 18 years, indicate that a relation subsists between the changes in the Sun's surface and the

[y] See the statistics on which this is based in *Proc. Lit. and Phil. Soc. of Manchester*, vol. xi. p. 111. They are summarised in *Month. Not.*, vol. xxxiii. p. 249. Feb. 1873.

[z] *Comptes rendus*, vol. lxxvii. p. 1226. 1873.

height of the water in the Lake. This latter element is to be viewed of course as indicative of the amount of precipitation that has taken place. Mr. Elvins's general conclusions are that years of maxima and minima of Sun-spots are years of small rainfall and low temperature. He considers, however, that the year immediately preceding a maximum or minimum is usually a specially wet year. If future observations should confirm these ideas, it will (among other things) follow that the rainfall curve is more abrupt than the Sun-spot curve. As regards there being a cycle for storms, Elvins confirms Pöey [a].

Some recent investigations by an American meteorologist named Brocklesby, of observations extending over 60 years, have led him to consider that in 3 cases out of 5, years of maximum spot energy are years of excess of rainfall; years of minimum spot energy to the number of 5 being, on the other hand, years noticeable in *every* case for deficiency of rainfall. He considers that his inquiries justify the general deduction that "the rainfall tends to rise above the mean when the Sun-spot area is in excess, and to fall below when there is a deficiency of solar activity [b]."

Professor C. P. Smyth is amongst those who have paid much attention to the subject of Sun-spot cycles and terrestrial temperatures. He considers that a great wave of heat passes over the Earth "every 11 years and a fraction, and *nearly coincidentally with the beginning of the increase of each Sun-spot cycle* of the same 11-year duration. The last observed occurrences of such heat-wave (which is very short-lived, and of a totally different shape from the Sun-spot curve), were in 1834·8, 1846·4, 1857·8, 1868·8, whence, allowing for the greater uncertainty in the earlier observation, we may expect the next occurrence of the phenomenon in or about 1880.0." Somewhat less pronounced than the foregoing is *the extreme cold close on either side of the great heat-wave.* Professor Smyth, writing in February, 1872, said, "We may perhaps be justified in concluding that the minimum temperature of the present cold wave was reached in 1871·1, and that the next similar cold wave will occur in 1878·8." Finally, between the dates of these 2 cold-waves there are 3 "*moderate*" and nearly equi-distant

[a] *Ast. Register*, vol. x. pp. 171, 221, and 265. 1872.

[b] *Silliman's Journal*, vol. viii. (3rd s.) p. 447. Dec. 1874.

heat-waves, with their 2 intervening and "*very moderate*" cold-waves[c].

Stone[d], making use of observations at the Cape of Good Hope, extending over 30 years, and Abbe[e], of observations at Munich, extending over 60 years, both trace a connection between the Sun-spot period and terrestrial temperatures. Stone's conclusion, based upon a comparison of curves, is thus expressed by himself:—"I cannot but believe that the same cause which leads to an excess of mean annual temperature leads equally to a dissipation of solar spots." Abbe's conclusion is that there is "a decrease in the amount of heat received from the Sun during the prevalence of the spots." Observations at Oxford (1864–70) show that the mean azimuthal direction of the wind there varied year by year through a range of 58° on the whole, between maximum and minimum of Sun-spots, the tendency of the wind to a *westward* direction increasing with the increase of the spots.

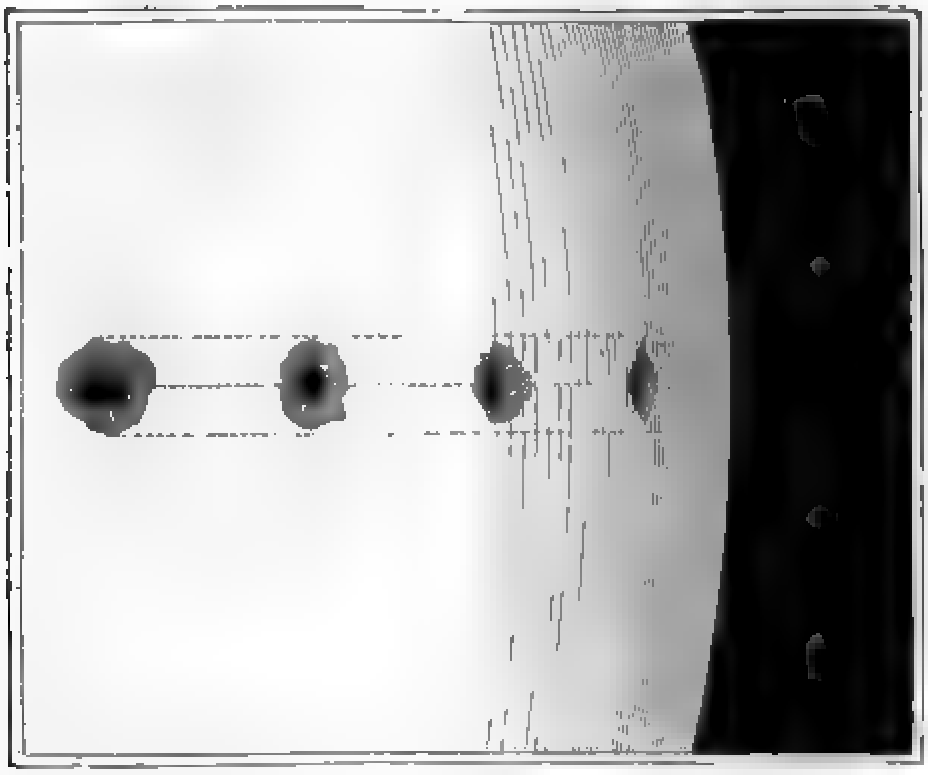
The only other observation which it appears necessary to cite here is by Ballot of Utrecht. He thinks he has established (by means of thermometric observations made at Haarlem, Zwanenbourg, and Dantzic, during a great number of years) the fact that at each period of $27{\cdot}7^{d}$ (that of the Sun's *visual* axial rotation) there is in these localities a small elevation of temperature, and a depression at the intermediate epochs.

Respecting the physical nature of the spots much uncertainty exists. Up to a comparatively recent period the generally received opinion, however, was that first enunciated by Professor Wilson of Glasgow in 1779, as modified by Sir W. Herschel—namely, that the Sun is surrounded by two atmospheres, of which the upper one is luminous (thence usually termed, after Schröter, the *photosphere*), and the under one, nearest to the Sun's surface, is non-luminous, and that the spots are rents or apertures in these atmospheres through which we see the solid body of the Sun, otherwise known to us as the "nucleus" of the spots. This idea is supported by the fact that, when near either limb, the spots are narrower (fore-shortened) than when seen directly in the centre of the disc. The lower stratum is assumed to receive some illumination from the photosphere, and thus to appear *penumbral;*

[c] *Nature*, vol. v. p. 317. Feb. 22, 1872.
[d] *Proc. Roy. Soc.*, vol. xix. p. 391. 1871.
[e] *Silliman's Journal*, vol. 50. (2nd s.) p. 345. Nov. 1870.

to occupy, in the matter of luminosity, a medium position between the photosphere reflecting much light, and the solid matter reflecting *little*, or, *perhaps*, none at all. The temporary removal

Fig. 16.



CHANGE OF FORM IN SPOTS OWING TO THE SUN'S ROTATION.

of both the strata, but more of the upper than of the lower, he conceived to be effected by powerful upward atmospheric currents, the origin of which is unknown. All, however, that now appears certain is that the nucleus of a spot is lower than the penumbra, and that both are beneath the level of the Solar photosphere. Detached masses of luminous matter are seen actually to cross a spot without producing any alteration in it. It would seem also that the gases in the space occupied by a spot are at an appreciably lower temperature than those in the brighter parts of the Sun,—but this at present represents practically the sum of our actual knowledge. That movements of a cyclonic character sometimes occur on the Sun, is sufficiently shown by a well-known drawing made by Secchi on May 5, 1857, of a spot in which a spiral motion is perfectly obvious. Above these atmospheres it is strongly believed that a thin and gaseous envelope exists, more nearly akin to what we understand by the word "atmosphere" as applied to the envelope which surrounds the Earth; and this supposition finds

confirmation in the fact that the margin of the Sun's disc is in general less luminous than the centre—a very obvious result on this hypothesis.

As regards the luminosity of the Sun's disc at the edge and at the centre, Laplace gives the ratio at 30 to 48; Arago at 40 to 41. The latter figures very greatly underrate the inequality. Secchi, taking the centre at 1, says that the margin is only $\frac{1}{3}$rd or $\frac{1}{4}$th as bright. He adds that he has found himself impeded in his investigations by a ruddiness in the light near the limb. Vogel, the most recent, and, it may be added, the most methodical investigator of this subject, obtained by a photographic expedient the following results; taking the Sun's radius at 12 and the brightness at the centre at 100, the brightness was found to lessen thus:—

Centre	=	100.
4	=	96.
8	=	77.
10	=	51.
Edge	=	13.

Representing the general brightness of the Sun's disc by 1000, according to Sir W. Herschel that of the penumbræ is 469 and of the nuclei only 7.

The chemical rays given out by different parts of the surface of the Sun also appear to be of unequal power, but, unlike the rays of light, they do not vary *regularly* from centre to edge.

As regards the rays of heat, these likewise are radiated more from the centre than from the edges. The Polar regions, too, are colder than the Equatorial, and Secchi has shewn that the heat radiated from the spots is less than that from the disc generally. Sir J. Herschel believes one hemisphere to be hotter than the other. That the luminous envelope of the Sun is an incandescent gas, Arago's Polariscope experiment is held to prove[g]. Sir John Herschel has shewn that Arago's experiments were by no means conclusive, but spectroscopic observations have brought this matter more directly before us.

Schwabe's observations seem to indicate that at epochs of minimum spot-display the Sun's surface is more uniformly bright than at other times; that is to say, that there is less absorption or

[g] See his *Pop. Ast.*, vol. i. p. 419.

enfeeblement of the Solar light towards the margin of the Sun's disc than usually is the case.

Spots on the Sun seem to have been discovered by J. Fabricius[h] and Galileo, independently, early in 1611, and by Harriot, also independently, in December of the same year. It will readily be understood that the observation of them was one of the first discoveries resulting from the invention of the telescope, though as spots large enough to be visible to the naked eye are often visible, they were occasionally seen before that event. Adelmus, a Benedictine monk, makes mention of a black spot on the Sun on March 17, 807[i]. It is also stated that a similar spot was seen by a Spanish Moor named Averroës, in the year 1161[k]. An instance of a solar spot is recorded by Hakluyt. He says, that in December 1590, the good ship "Richard of Arundell" was on a voyage to the coast of Guinea, and that her log states that "on the 7 at the going downe of the sunne, we saw a great blacke spot in the sunne, and the 8 day, both at rising and setting, we saw the like, which spot to our seeming was about the bignesse of a shilling, being in 5 degrees of latitude, and still there came a great billow out of the southerboard[l]." The spot was also observed on the 16th.

The natural purity of the Sun seems to have been an article of faith with the ancients, on no account to be called in question; so that we find that when Scheiner (who was a Jesuit at Ingolstadt) reported to his Superior what he had seen, the idea was treated as a delusion. "I have read," replied the Superior, "Aristotle's writings from end to end many times, and I can assure you that I have nowhere found anything in them similar to what you mention. Go, my son, tranquillize yourself; be assured that what you take for spots in the Sun are the fault of the glasses or of your own eyes." Scheiner in the end, though permitted to publish his opinions[m], was obliged to do so anonymously, so great

[h] An interesting account of Fabricius's first observations of a spot on the Sun will be found in Guillemin's *Sun*, p. 127, Eng. Ed.

[i] Bede; Polydore Virgil.

[k] *Commentary on the Almagest*, quoted by Copernicus, *De Revol. Orb. Cel.*, lib. x.

[l] *The Principal Navigations, Voiages, Traffiques, and Discoveries of the English Nation, &c.*, vol. ii. p. 131. London, 1599.

[m] *Rosa Ursina, &c.* Alluding to this enormous book, Delambre says: "There are few books so diffuse and so void of facts. It contains 784 pages; there is not matter in it for 50 pages."—*Hist. Ast. Mod.*, vol. i. p. 690. Either printing must have been cheap or authors rich in those days.

were the difficulties with which he had to contend as a member of the Church of Rome.

In addition to spots, streaks of light may frequently be remarked upon the surface of the Sun towards the equatorial margin of the disc. These are termed *faculæ* [o], and are generally found near spots (just outside the penumbræ) or where spots have previously existed or are afterwards about to appear; when near the limb of the Sun they are more or less parallel to it. They are of irregular form, and may be likened somewhat to certain kinds of coral, and are more luminous than the solar surface surrounding them. Secchi considers that they are not brighter than the centre of the Sun. They are elevations or ridges in the photosphere, as is proved by Dawes having seen one project above the limb in turning the (apparent) corner into the invisible hemisphere [p]. Sir W. Herschel saw a facula on December 27, 1799, 2′ 46″ or 72,000 miles long [q]. They are first alluded to by Galileo in his third letter to Welser [r].

Fig. 17.

Ideal View of the Facular Structure of the Sun.

Brayley has suggested that faculæ and red prominences are manifestations of the same phenomenon, seen in the former case in front of and in the latter outside the Sun's disc. It has been objected that faculæ are never seen except in the vicinity of the Sun's equator, but the reply is that for some unknown reason a polar position may interfere with their visibility for a front view.

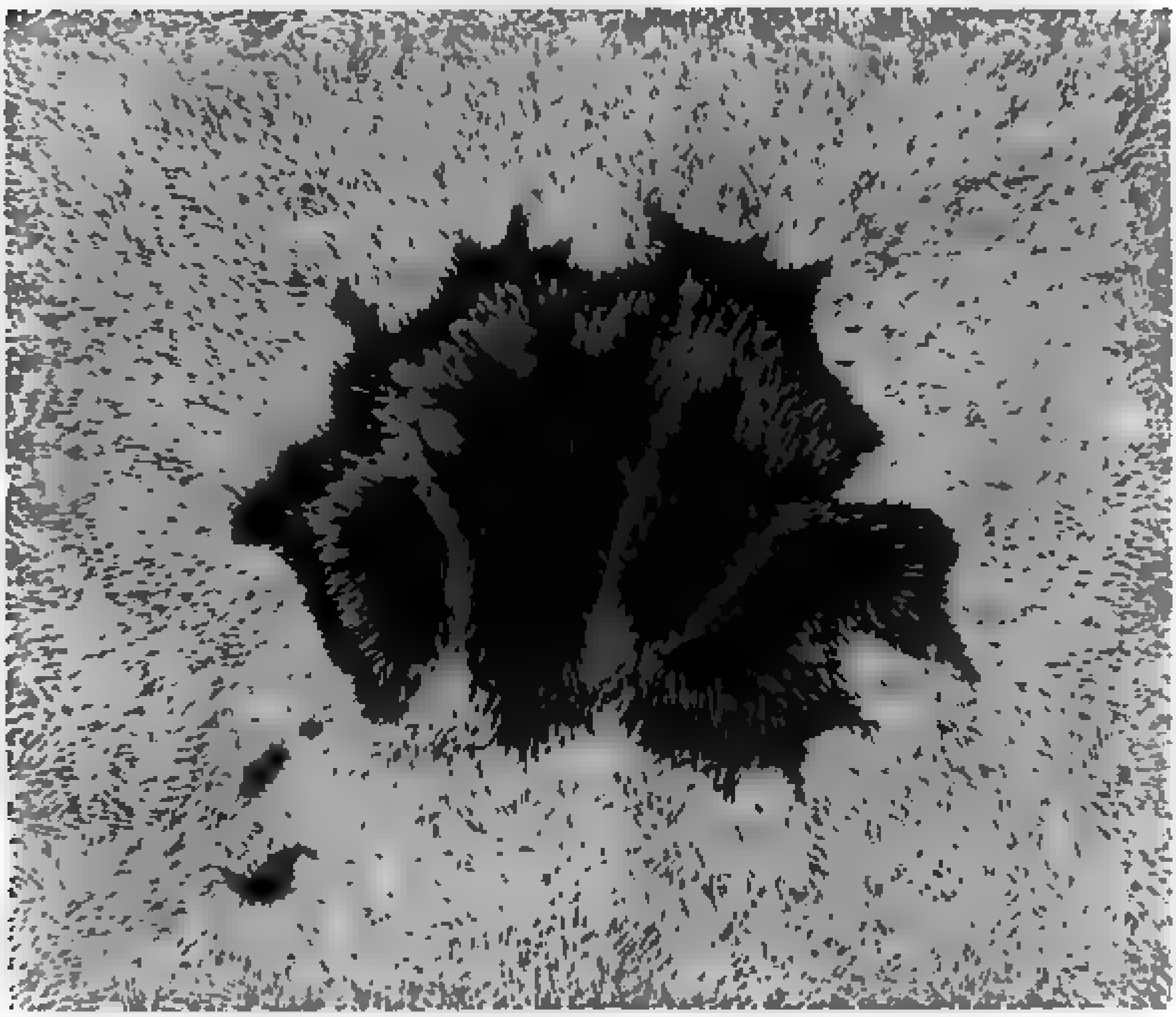
The surface of the Sun is frequently found to be covered with irregular specks of light, presenting a mottled appearance not unlike that of the skin of an orange, but relatively much less coarse. This phenomenon prevails most in the regions to which the spots belong, but its cause is unknown. Short, the optician, seems to have first noticed it during the eclipse of July 14, 1748 (o. s.). The term *luculi* [s] has been applied to the constituent specks.

[o] Latin *facula*, a torch.
[p] *Month. Not.*, vol. xx. p. 56. Dec. 1859.
[q] *Phil. Trans.*, vol. xci. p. 293. 1801.
[r] *Istoria e Dimostrazioni intorno alle Macchie Solari*, p. 131. Rome, 1613.
[s] Latin *lucus*, a shining.

Schwabe finds that faculæ and luculi are usually absent at epochs of spot minima [t].

Of late years the Sun has received an unusual amount of attention from astronomers, and a variety of interesting facts have been brought to light concerning its physical appearance. In 1860 Mr. Nasmyth with his great reflector (alluded to in a later place) ascertained, it would seem for the first time, that the Sun's surface is covered with a tolerably compact agglomeration of entities, which he likened to *willow leaves*; that is to say,

Fig. 18.



SPOT ON THE SUN, JULY 29, 1860, SHEWING THE "WILLOW-LEAF" STRUCTURE. (*Nasmyth.*)

they presented to his eye an appearance similar to that which a rather thin but flattened layer of willow leaves might be expected to exhibit.

As an acrimonious controversy arose in regard to this alleged discovery, it may be fair to lay before the reader Mr. Nasmyth's own statement on the subject.

[t] *Month. Not.*, vol. xxvii. p. 286. June 1867.

"In order to obtain a satisfactory view of these remarkable objects, it is not only requisite to employ a telescope of very considerable power and perfection of defining capability, but also to make the observation at a time when the atmosphere is nearly quite tranquil, and free from those vibrations which so frequently interpose most provoking interruptions to the efforts of the observer; without such conditions as I allude to, it is hopeless to catch even a glimpse of these remarkable and delicate details of the solar surface.

* * * * * * * * * * *

"The filaments in question are seen, and appear well defined, at the edges of the luminous surface, where it overhangs 'the penumbra,' as also in the details of the penumbra itself, and most especially are they seen clearly defined in the details of 'the bridges,' as I term those bright streaks which are so frequently seen stretching across from side to side over the dark part of the spot. So far as I have as yet had an opportunity of estimating their actual magnitude, their average length appears to be about 1000 miles, the width about 100.

"There appears no definite or symmetrical arrangement in the manner in which they are scattered over the surface of the Sun; they appear to be across each other in all possible variety of directions. The thickness of the layer does not appear to be very deep, as I can see down through the interstices which are left here and there between them, and through which the dark or penumbral stratum is rendered visible. It is the occurrence of the infinite number of these interstices, and the consequent visibility of a corresponding portion of the dark or penumbral stratum, that gives to the general solar surface that peculiar and well-known mottled appearance which has for a long time been familiar to the observers of the Sun.

"When a solar spot is mending up, as was the case with the one represented, these luminous filaments or willow-leaf-shaped objects (as I term them) are seen to pass from the edges and extend across the spots, thus forming 'the bridges,' or bright streaks across the spots; if these are carefully observed under favourable conditions, the actual form of these remarkable details, of which 'the bridges' are composed, will be revealed to sight.

"Subsequent observations and considerations of the subject have not caused me to desire to modify or alter the description in the letter above referred to [u]; but only to confirm me in its general correctness. I have no desire to embark in any controversy on the subject, as I prefer to leave to the Sun itself, when carefully observed by adequate means and on favourable occasions, the complete confirmation of what I claim to be the first to discover, delineate, and accurately describe in reference to the structure of his entire luminous surface, as well as the precise form of the structural details, which, from their general similitude in respect to *form*, I at once compared with *willow leaves* [x]."

Mr. Nasmyth's views were much canvassed. Several eminent observers of unquestioned good faith, and possessed of first-class instruments and great experience, declared the alleged conformation of the solar surface a myth, whilst others, equally entitled to

[u] *Month. Not.*, vol. xxiv. p. 66. Jan. 1864.

[x] The preceding paragraphs are taken from a letter reproduced by Nasmyth himself, with a brief supplementary note appended.

be heard with respect, avouched their belief in the reality of the discovery. I believe it to be an impartial summing up of the whole case *pro* and *con* to say that there is a very general agreement that innumerable detached (?) masses of unknown nature are scattered over the Sun's surface, and that whether "willow leaves," "rice grains," "granulations," or "shingle beach," be employed to designate them, is rather a matter of taste than evidence of

Fig. 19.

SPOT ON THE SUN, JANUARY 20, 1865. (*Secchi.*)

substantial variance. Further, that in the main they do partake of an elliptic outline, and that the average ratio of the axes, whether it be 10 to 1, as Nasmyth first had it, or 4, 3, or 2 to 1, as other observers have since stated it, is, after all, the main point concerning which issue is joined, and even here apparent discrepancies might be ascribable to actual physical change in the bodies themselves.

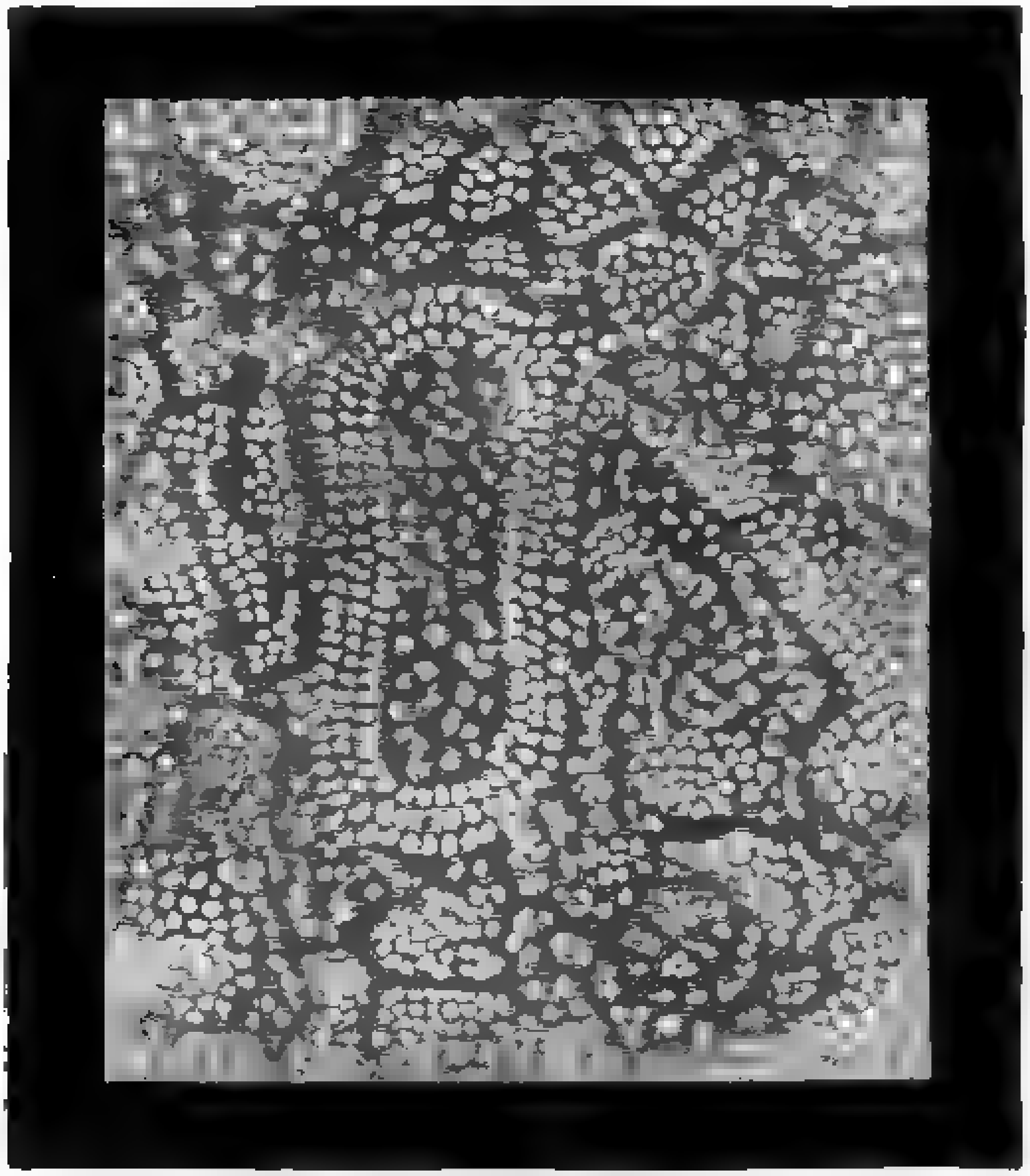
A valuable synopsis of the question was presented to the Royal

Astronomical Society in 1866 by Huggins[y]. The following is a brief summary of its contents:—

1. *Granule* is the best word to describe the luminous particles on the Sun's surface, as no positive form is thereby implied.

2. The granules are seen all over the Sun, including (occasionally) the surfaces of umbræ and penumbræ. More rarely they can be detected in faculæ.

Fig. 10.



Ideal View of the "Granular" Structure of the Sun. (*Huggins.*)

3. With low powers "rice grains" is a very suitable expression for these granules, but the regularity implied in this designation disappears to a great extent under high magnifiers. There is however, undoubtedly, a general tendency to an oval contour.

4. The average size of the more compact granules is 1″, of those

[y] *Month. Not.*, vol. xxvi. p. 260. May 1866.

more elongated $1\frac{1}{2}''$, a few might be $3''$, many less than $1''$. They appear to be not flat discs but bodies of considerable thickness.

5. The granules are sometimes packed together rather closely in groups of irregular and straggling outline; at other times they are sparsely scattered. The well-known "mottling" arises wholly from the latter species of combination.

6. The Sun's surface is by no means uniformly level. The whole photosphere appears corrugated into irregular ridges and vales, and the granules are possibly masses of rather dense cloud-like matter floating about in the photosphere, considered as composed of more aëriform matter. If the granules really are incandescent clouds, their general oval form may be due to the influence of currents.

The accompanying figure [20] shews some of the most characteristic modes of grouping of the bright granules noticed by Mr. Huggins on different occasions and on various parts of the Sun's surface, brought together, however, in one wood-cut for convenience of comparison.

To the cloudy stratum giving rise to the penumbræ Petit assigns a depth exceeding 4000 miles. On the other hand Phillips considered 300 miles a probable amount. Neither figure is *primâ facie* entitled to much consideration.

Sir W. Herschel supposed that one of the hemispheres of the Sun is by its physical constitution less adapted to emit light and heat than the other, but the grounds of this conclusion are not known.

Of late years the study of the sun has taken a remarkable start, owing to the fact that by the aid of the spectroscope we have been enabled to obtain much new information about the physical constitution of the Sun. The subject being, however, a physical rather than an astronomical one, and involving a great amount of chemical and optical detail, it cannot conveniently be discussed at length in an astronomical treatise, though something will be said concerning it later on in this work.

CHAPTER II.

THE PLANETS.

Epitome of the motions of the Planets.—Characteristics common to them all.—Kepler's laws.—Elements of a Planet's orbit.—Curious relation between the distances and the periods of the Planets.—The Ellipse.—Popular illustration of the extent of the Solar system.—Bode's law.—Miscellaneous characteristics of the Planets.—Curious coincidences.—Conjunctions of the Planets.—Conjunctions recorded in History.—Statistical Tables of the Major Planets.—Different systems.—The Ptolemaic system.—The Egyptian system.—The Copernican system.—The Tychonic system.

AROUND the Sun, as a centre, certain bodies called Planets [a] revolve at greater or less distances. They may be divided into two groups, (1) the "inferior" planets, or those whose orbits are within that of the Earth—Mercury and Venus; and (2) the "superior" planets, or those whose orbits are beyond that of the Earth—Mars, the Minor Planets, Jupiter, Saturn, Uranus, and Neptune.

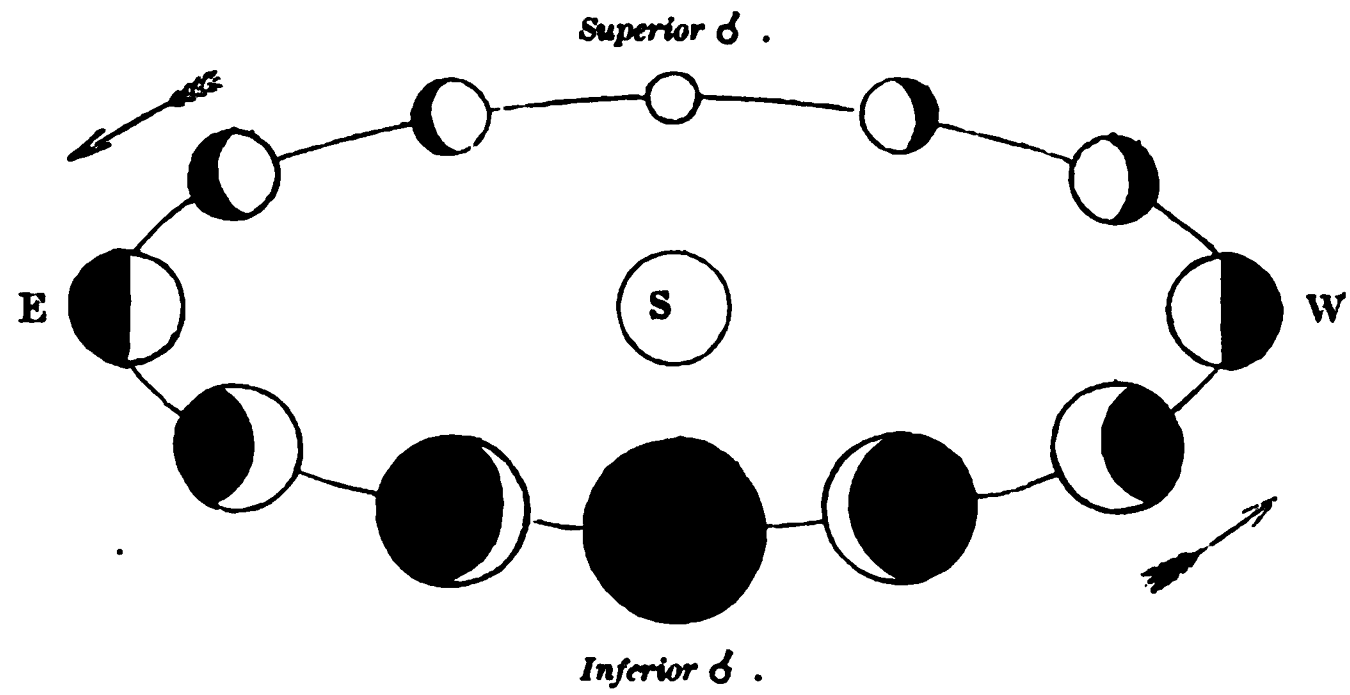
If viewed from the Sun *all* the planets would appear to the spectator to revolve round that luminary in the order of the zodiacal signs; such, however, cannot be the case when the observation is made from one of their number itself in motion, and therefore to us on the Earth the planets *appear* to travel in a capricious manner; and, further, the inferior and superior planets differ the one class from the other in their visible movements.

The Inferior planets are never seen in those parts of the heavens which are in opposition to the Sun; in other words they are never on the meridian at midnight, being always within a short angular distance of the Sun, to the East or West of it as the case may be.

[a] πλανήτης, a wanderer.

Twice in every revolution an inferior planet is in *conjunction* with the Sun [Fig. 21]; in *inferior conjunction* when it comes between the Earth and the Sun, and in *superior conjunction* when the Sun intervenes between the Earth and the planet. When it attains its greatest distance (as we see it) from the Sun, East or West, it is said to be at its *greatest elongation*, East or West, as the case may be. In the former case the planet is an "evening star," in the latter a "morning star."

Fig. 21.



PHASES OF AN INFERIOR PLANET.

Although a planet always truly moves in the order of the signs, yet there are periods when it appears *stationary;* sometimes even its motion appears *retrograde* or reversed. These peculiarities are owing to the fact that the Earth has simultaneously a motion of its own in its orbit; and it will readily be understood that they are only apparent and not real. They also obtain with the superior planets. It sometimes (though very rarely) happens that an inferior planet, when in inferior conjunction, passes directly between the Earth and the Sun, and is consequently projected on the disc of the latter, which it crosses from East to West: this phenomenon is termed a *transit*[b]; the particular elucidation of which belongs to Book II., (*post*).

A superior planet can have any angular distance from the Sun not greater than 180°. After starting from conjunction with the Sun it successively reaches its Eastern quadrature (at an

[b] *Transire*, to go across.

angular distance of 90°); and its opposition at 180°. Proceeding onwards it comes to its Western quadrature, 270° from the Sun *reckoned in the direction of its motion*, but only 90° reckoned in the other direction. Another stage of 90° brings it again into conjunction. A planet cannot have a greater angular distance from the Sun than 180°, because when that is attained it begins to approach the Sun again on the other side, for an obvious geometrical reason.

A full account of the motions of the planets does not fall within my scope, but the books named in the note may be consulted [c].

There are certain characteristics common to all the planets, which are thus enunciated by Hind :—

1. *They move in the same invariable direction round the Sun; their course, as viewed from the north side of the ecliptic, being contrary to the motion of the hands of a watch.*

2. *They describe oval or elliptical paths round the Sun, not however differing greatly from circles.*

3. *Their orbits are more or less inclined to the ecliptic, and intersect it in two points, which are the "nodes;" one half of the orbit lying north, and the other half south of the Earth's path.*

4. *They are opaque bodies like the Earth; and shine by reflecting the light which they receive from the Sun.*

5. *They revolve upon their axes in the same way as the Earth. This we know by telescopic observation to be the case with many planets, and, by analogy, the rule may be extended to all. Hence they will have the alternation of day and night, like the inhabitants of the Earth; but their days are of different lengths to our own.*

6. *Agreeably to the principles of gravitation, their velocity is greatest at those parts of their orbit which lie nearest the Sun, and least at the opposite parts which are most distant from it; in other words, they move quickest in perihelion* [d], *and slowest in aphelion* [e].

From a long series of observations of the planet Mars, Kepler found that certain definite laws might be deduced relative to the motions of the planets, which may be thus stated :—

1. *The planets move in ellipses, having the Sun in one of the foci.*

[c] Sir J. Herschel's *Outlines of Ast.*, p. 301 *et seq.*; Hind's *Introd. to Ast.*, p. 63 *et seq.* (very good).

[d] περὶ round, and ἥλιος the Sun.

[e] ἀπὸ from, and ἥλιος. The fact here referred to is more strikingly manifest in the case of a comet, owing to the greater eccentricity of cometary orbits: the velocity of Donati's comet at perihelion is 127,000 miles per hour, but at aphelion only 480 miles per hour.—(Hind, Letter in the *Times*, Oct. 25, 1858.)

2. ***The radius vector of each planet describes equal areas in equal times.***

3. ***The squares of the periodic times of the planets are proportional to the cubes of their mean distances from the Sun.***

These laws hold good for all the planets and all their satellites. I have already referred in general terms to the first law; it may, however, be desirable to say that the orbit of a planet with reference to its form, magnitude, and position, is determined by the five following data or *elements*:—

1. *The longitude of perihelion*, or the longitude of the planet, when it reaches this point,—denoted by the symbol π.

2. *The longitude of the ascending node* of the planet's orbit, as seen from the Sun.—☊.

3. *The inclination of the orbit*, or the angle made by the plane of the orbit with the ecliptic.—ι.

4. *The eccentricity*.—ϵ. This is sometimes expressed by the angle ϕ, of which ϵ is the natural sine.

5. *The semi-axis-major*, or *mean distance*.—a.

And in order to compute the place of a planet at any given moment, we further need to know,

6. Its *periodic time* (obtainable from (5) by Kepler's 3^{rd} law), and,

7. Its *mean longitude*, or place in its orbit, at a given epoch.

Fig. 22.

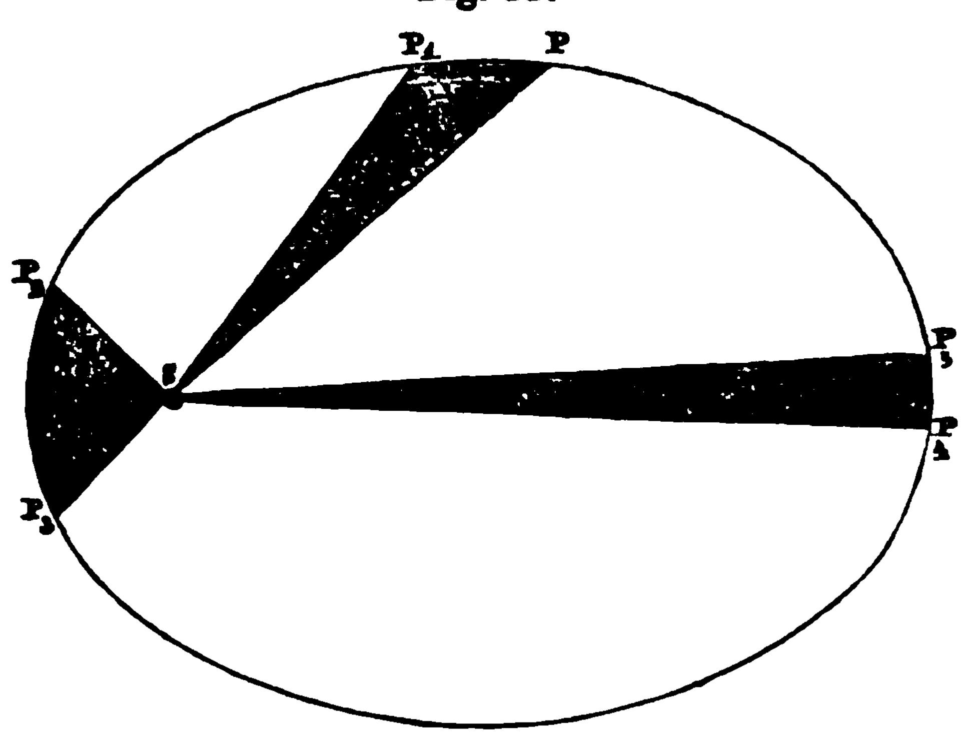


DIAGRAM ILLUSTRATING KEPLER'S SECOND LAW.

Kepler's 2^{nd} law will readily be understood from the annexed diagram. Let P P^2 P^4 be the elliptic path of a planet, and let it move from P to P^1, from P^2 to P^3, and from P^4 to P^5 in equal intervals of time; then the 3 shaded areas, which are assumed to correspond with the movement of the radius vector, will be equal.

The 3^{rd} law involves a curious coincidence, which may be thus expressed:—*If the squares of the periodic times of the planets be divided by the cubes of their mean distances from the Sun, the*

quotients thus obtained are the same for all the planets. The following table exemplifies this: it should be remarked, however, that the want of *exact* uniformity in the fourth column[f] is owing to inexactness in the observations on which the calculations are based, as also to the perturbations which the planets mutually exercise on each other's orbits:—

Planet.	a	p	$\frac{p^2}{a^3}$
Vulcan?	0·143	19·7	132716
Mercury	0·38710	87·969	133421
Venus	0·72333	224·701	133413
Earth	1·00000	365·256	133408
Mars	1·52369	686·979	133410
Ceres	2·77692	1679·855	132210
Jupiter	5·20277	4332·585	133294
Saturn	9·53858	10759·220	133375
Uranus	19·18239	30686·821	133422
Neptune	30·03627	60126·722	133413

This law also holds good for the satellites[g], as will be seen from the following tables calculated for the purpose of exemplifying it.

THE SATELLITES OF SATURN.

Name.	a	p	$\frac{p^2}{a^3}$
Mimas	3·36	0·94	23295
Enceladus	4·31	1·37	23443
Tethys	5·34	1·89	23458
Dione	6·84	2·74	23460
Rhea	9·55	4·52	23457
Titan	22·14	15·95	23442
Hyperion	26·86	21·30	23412
Iapetus	64·54	79·33	23409

[f] The decimal pointing is neglected in all cases in the 4th column, that the eye-appreciation of the coincidences may not be interfered with.

[g] This is not rigorously true when the mass of the planet has an appreciable ratio to that of the Sun.

THE SATELLITES OF JUPITER.

No.	a	p	$\frac{p^2}{a^3}$
I.	6·05	1·77	14147
II.	9·62	3·55	14156
III.	15·35	7·15	14135
IV.	26·99	16·69	14168

THE SATELLITES OF URANUS.

No.	a	p	$\frac{p^2}{a^3}$
I.	6·94	2·51	18848
II.	9·72	4·14	18664
III.	15·89	8·70	18909
IV.	21·27	13·46	18827

Kepler's laws are the foundation of all planetary astronomy, and it was from them that Newton deduced his theory of gravitation. Arago says: "These interesting laws, tested for every planet, have been found so perfectly exact, that we do not hesitate to infer the distances of the planets from the Sun from the duration of their sidereal revolutions; and it is obvious that this method of estimating distances possesses considerable advantages in point of exactness; for it is always easy to determine precisely the return of each planet to a point in the heavens, while it is very difficult to determine exactly its distance from the Sun."

Sir J. Herschel discusses the theoretical considerations connected with these laws with great perspicuity; and the reader will do well to consult his remarks[h].

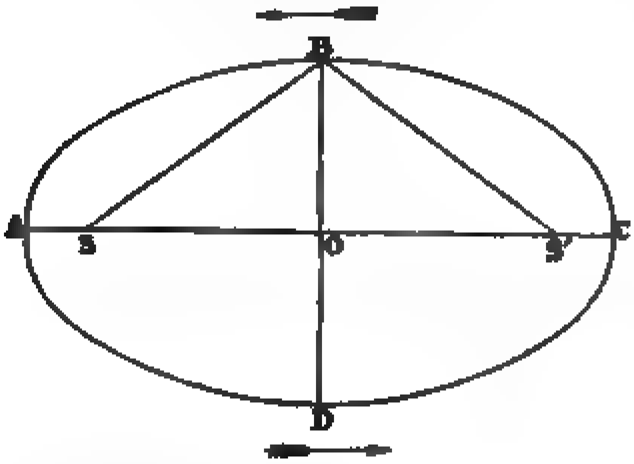
A few definitions as to the properties of an ellipse will here be appropriate.

In figure 23, S and S′ are the *foci* of the ellipse; A C is the *major axis;* B D the *minor* or *conjugate axis;* O the *centre:* or, astronomically—O A is the *semi-axis-major* or *mean distance,* O B the *semi-axis-minor;* the ratio of O S to O A is the *eccentricity:*

[h] *Outlines of Ast.*, pp. 322–7.

the least distance, S A, is the ***perihelion distance;*** the greatest distance, S C, the ***aphelion distance.*** S B O is the angle ϕ referred to on p. 41. Where an eccentricity is stated in the form of a vulgar fraction, O S is the numerator and O A the denominator. A decimal expression is to the like effect.

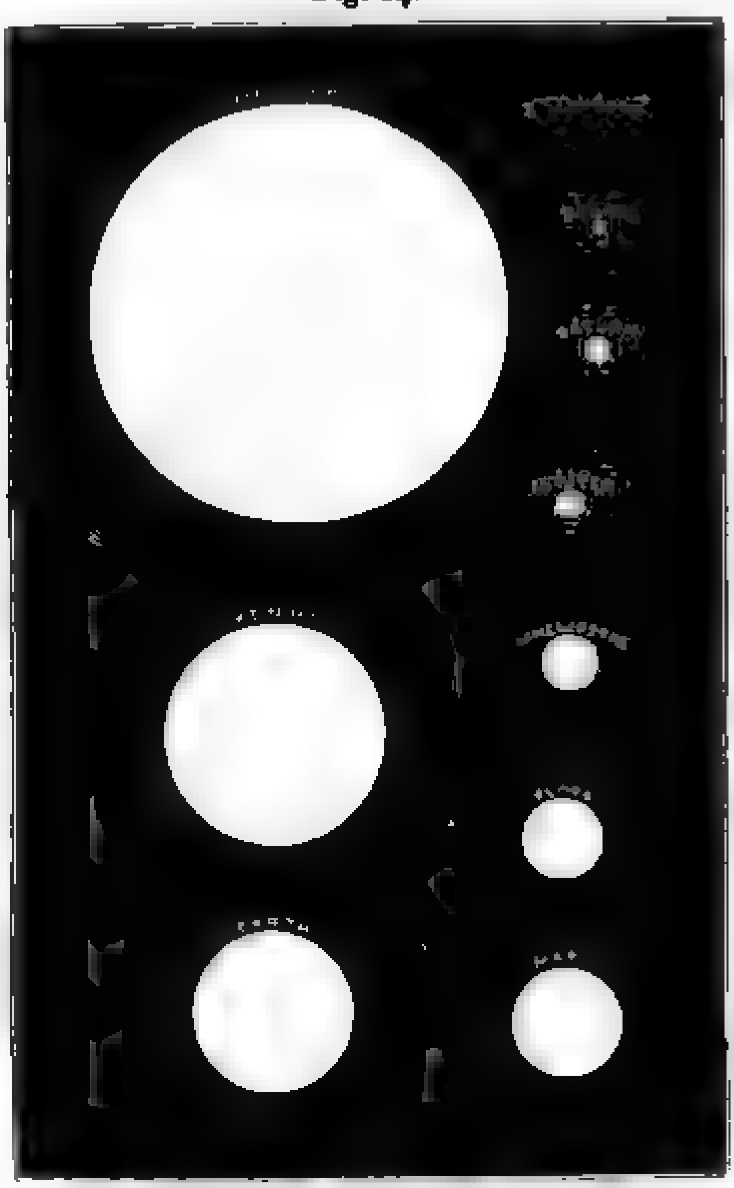
Fig. 23.



The Ellipse.

It will not be difficult to follow in the mind the additional characteristics of a planetary orbit. The orbit in the figure is laid down on a plane surface; incline it slightly as compared to some fixed plane ring and the element of the inclination (as regards its amount) will present itself. (The astronomical fixed plane in this case is that of the ecliptic.) Imagine a planet following the inclined ellipse; at some point it must rise above the level of the fixed plane: the point at which it begins to do so, measured angularly from some settled starting-point, gives the ***longitude of the ascending node.*** Then the planet's position in the ellipse when it comes closest to the principal focus, gives us, when projected on the plane ring, the place of nearest appulse to the focus, in other words, the ***longitude of the perihelion.*** Follow-

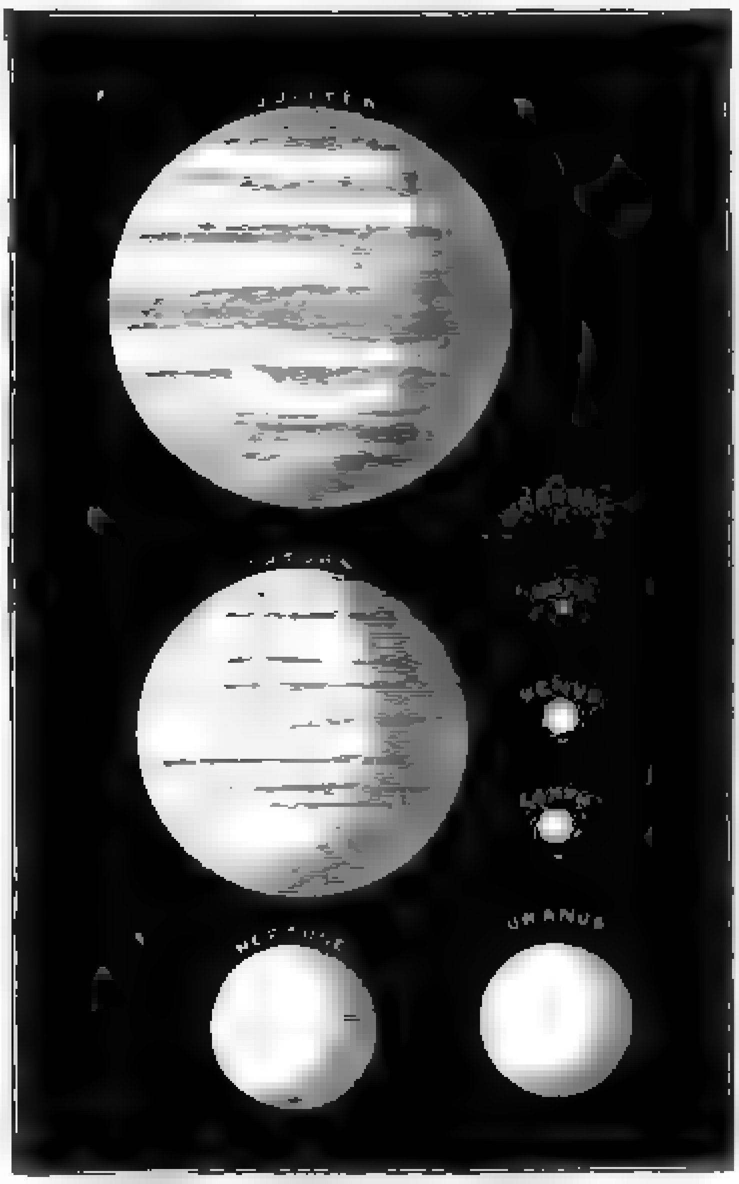
Fig. 24.


Relative apparent Size of the Sun, as viewed from the different Planets.

ing these steps, it is not a matter of much difficulty to form a general conception of a planetary orbit in space, for though the method is perhaps rather crude, it is so far strictly accurate.

The following scheme will assist the reader to obtain a correct notion of the magnitude of the planetary system. Choose a level field or common; on it place a globe 2 feet in diameter, for the Sun; Vulcan (?) will then be represented by a small pin's head, at a distance of about 27 feet from the centre of the ideal Sun; Mercury by a mustard seed, at a distance of 82 feet; Venus by a pea, at a distance of 142 feet; the Earth also by a pea, at a distance of 215 feet; Mars by a small pepper-corn, at a distance of 327 feet; the minor planets by grains of sand, at distances varying from 500 to 600 feet: if space will permit, we may place a moderate-sized orange nearly ¼ mile distant from the starting-point to represent Jupiter; a small orange ⅖ of a mile for Saturn; a full-sized cherry ¾ mile distant for Uranus; and lastly a plum 1¼ miles off for Neptune, the most distant planet yet known.

Fig. 25.



COMPARATIVE SIZES OF THE PLANETS.

Extending this scheme, we should find that the aphelion distance of Encke's Comet would be at 880 feet; the aphelion distance of Donati's Comet of 1858 at 6 miles; and the nearest fixed star at 7500 miles.

According to this scale the daily motion of Vulcan (?) in its orbit would be 4⅜ feet; of Mercury 3 feet; of Venus 2 feet; of the Earth 1⅞ feet; of Mars 1½ feet; of Jupiter 10½ inches; of Saturn

7½ inches; of Uranus 5 inches; and of Neptune 4 inches. These figures illustrate also the fact that the orbital velocity of a planet decreases as its distance from the Sun increases.

Connected with the distances of the planets, Bode of Berlin in 1778 published the following singular "law" of the numerical relations existing between them, which, although not discovered by him but by Titius of Wittemberg, usually bears his name.

Take the numbers—

0 3 6 12 24 48 96 192 384;

each of which (the second excepted) is double the preceding; adding to each of these numbers 4, we obtain

4 7 10 16 28 52 100 196 388;

which numbers approximately represent the distances of the planets from the Sun expressed in radii of the Earth's orbit, as exhibited in the following table:—

Planets.	True Distance from ☉	Distance by Bode's Law.
Mercury	3·87	4·00
Venus	7·23	7·00
Earth	10·00	10·00
Mars	15·23	16·00
Ceres	27·66	28·00
Jupiter	52·03	52·00
Saturn	95·39	100·00
Uranus	191·83	196·00
Neptune	300·37	388·00

Bode having examined these relations, and noticing the void between 16 and 52 (Ceres and the other minor planets not being then known), ventured to predict the discovery of new planets; and it may reasonably be believed that this conjecture guided or induced the investigations of subsequent observers; though some have disputed this[i]. In the above table the greatest deviation

[i] As far back as 450 B.C. Democritus of Abdera thought it probable that eventually new planets would, perhaps, be discovered. (Seneca, *Quæst. Nat.*, lib. vii. cap. 3 and 13.) Kepler was of opinion that some planets existed between the orbits of Mars and Jupiter, but too small to be visible to the naked eye. The same philosopher conjectured that there was another planet between Mercury and Venus.

between the assumed and the true distance is in the case of Neptune; it is possible, however, that when more complete observations of this planet shall have been made, the above difference may be somewhat reduced. We may sum up Bode's law as follows: — *That the interval between the orbits of any two planets is about twice as great as the inferior interval, and only half the superior one*[k].

Separating the major planets into two groups, if we take Mercury, Venus, the Earth, and Mars as belonging to the interior; and Jupiter, Saturn, Uranus, and Neptune to the exterior group, we shall find that they differ in the following respects:—

1. The interior planets, with the exception of the Earth, are not, as far as we know, attended by any satellites, while the exterior planets *all* have satellites. We cannot but consider this as one of the many instances to be met with in the universe of the beneficence of the Creator—that the satellites of these remote planets are designed to compensate for the small amount of light their primaries receive from the sun, owing to their great distance from that luminary.

2. The average density of the first group considerably exceeds that of the second, the approximate ratio being 5 : 1.

3. The mean duration of the axial rotations, or mean length of the day, of the interior planets, is much longer than that of the exterior; the average in the former case being $23^h\ 58^m$, but in the latter only $10^h\ 12^m$.

In the Appendix will be found a full tabular summary of information concerning the Sun, Moon, and Major Planets, brought up to the latest possible date.

The following singular coincidences deserve to be mentioned:—

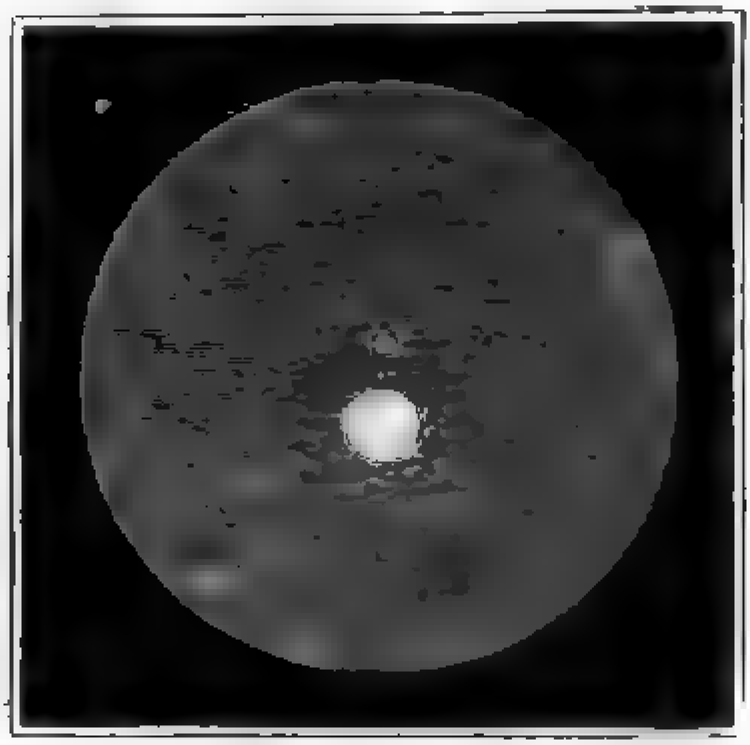
1. Multiply the Earth's diameter (7912 miles) by 108, and we get 854,496 = ± the Sun's diameter in miles.

2. Multiply the Sun's diameter (852,584 miles) by 108, and we get 92,079,072 = ± the mean distance of the Earth from the Sun.

[k] Many attempts have been made by ingenious dabblers in Astronomy to discover other arithmetical coincidences formed after the spirit of Bode's law. The following is the only one I have met with which deserves reproduction. Take the series 0, 1, 2, 4, 8, 16, 32, and 64: add 4 to each, and the resulting figures represent with some approach to accuracy the relative distances from their primary of the satellites of Saturn.

3. Multiply the Moon's diameter (2160 miles) by 108, and we get 233,280 = ± the mean distance of the Moon from the Earth.

Fig. 26.



Venus and Jupiter, July 21, 1859.

A phenomenon of considerable interest, especially on account of its rarity, is the conjunction, or proximity, of two or more planets within a limited area of the heavens. A noticeable instance is depicted in fig. 26. It occurred on the morning of July 21, 1859, when Venus and Jupiter came very close to each other; at 3^h 44^m A.M. the distance between the two planets was only 13″, and they accordingly appeared to the naked eye as one object.

On Jan. 29, 1857, Jupiter, the Moon, and Venus were in a straight line with one another, though not within telescopic range.

On Dec. 19, 1845, Venus and Saturn appeared in the same field of the telescope. [See fig. 27, next page.]

On Oct. 3, 1801, Venus, Jupiter, and the Moon were in close proximity in Leo, and Saturn was not far off.

On Dec. 23, 1769, Venus, Jupiter, and Mars were very close to each other.

On March 17, 1725, Venus, Jupiter, Mars, and Mercury appeared together in the same field of the telescope.

On Nov. 11, 1544, Venus, Jupiter, Mercury, and Saturn were enclosed in a space of 10°.

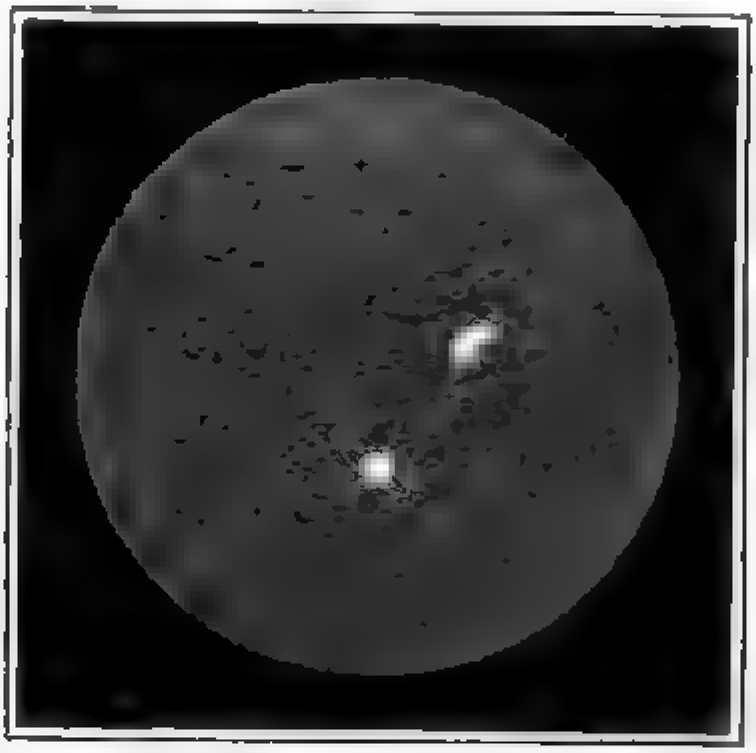
On Nov. 11, 1524, Venus, Jupiter, Mars, and Saturn were very close to each other, and Mercury was only 16° distant.

In the years 1507, 1511, 1552, 1564, 1568, 1620, 1624, 1664, 1669, 1709, and 1765, the three most brilliant planets—Venus, Mars, and Jupiter—were very near each other.

On Sept. 15, 1186, Mercury, Venus, Mars, Jupiter, and Saturn were in conjunction between the Wheat-ear of Virgo, and Libra.

The earliest record we possess of an occurrence of this kind is of Chinese origin. It is stated that a conjunction of Mars, Jupiter, Saturn, and Mercury, in the constellation *Shi*, was assumed as an epoch by the Emperor Chuen-hio, and it has been found by MM. Desvignoles and Kirch that such a conjunction actually did take place on Feb. 28, 2446 B.C., between 10° and 18° of Pisces[l]. Another calculator, De Mailla, fixes upon Feb. 9, 2441 B.C., as the date of the conjunction in question; and he states that the four planets named above, and the Moon besides, were comprised within an arc of 12°, extending from 15° to 27° of Pisces. It deserves mention that both the foregoing dates precede the Noachian deluge. It can therefore only be that the planetary conjunction in question was after-ascertained.

Fig. 27.



VENUS AND SATURN, Dec. 19, 1845.

De Mailla gives the following positions[m]:—

	R.A. °	′	″
Mercury	344	56	16
Jupiter	347	2	12
The Moon	353	18	21
Saturn	354	39	47
Mars	356	45	11

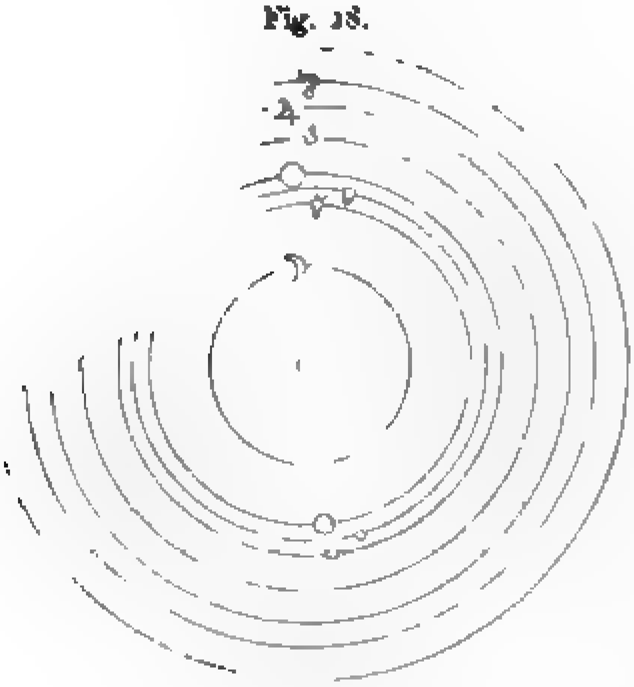
A few general remarks on the different theories of the solar system which have at various times been current will appropriately conclude this chapter.

[l] Bailly, *Astron. Ancienne*, p. 348. Desvignoles's original memoir appears in *Mém. de l'Acad. de Berlin*, vol. iii. p. 166, and Kirch's in vol. v. p. 193 of the same series.

[m] *Hist. Gén. de la Chine*, vol. i. p. 155.

The *Ptolemaic system* claims the first place in consequence of its wide acceptance and the fame of the astronomer whose name it bears. It would, however, be more correct to say that Ptolemy reduced it into shape rather than that he actually originated it. The earth was regarded as the centre, and around this the Moon (☽), Mercury (☿), Venus (♀), The Sun (☉), Mars (♂), Jupiter (♃), and Saturn (♄), all called *planets*, were assumed to revolve in the order in which I have given them.

Fig. 18.



The Ptolemaic System.

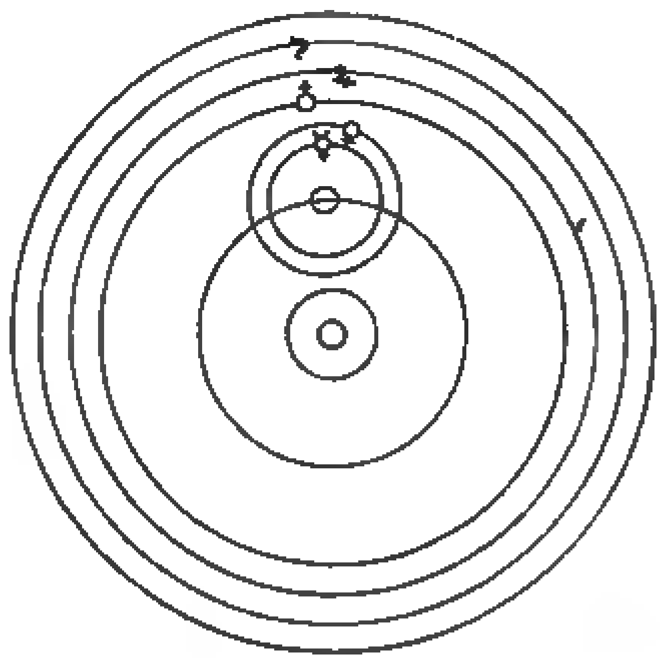
More accurate ideas were, however, current even before Ptolemy's time, but they found few supporters. Aristarchus of Samos, who lived about 280 B.C., supposed, according to Archimedes and Plutarch, that the Earth revolved round the Sun, for which "heresy" he was accused of impiety. Cleanthus of Assos, who flourished but 20 years later, was, according to Plutarch, the first who sought to explain the great phenomena of the universe by supposing a motion of translation on the part of the Earth around the Sun, together with one of rotation on its own axis. The historian relates that this idea was so novel and so contrary to the received notions that it was proposed to arraign Cleanthus also for impiety.

The *Egyptian system* differed from the Ptolemaic only in regarding Mercury and Venus as satellites of the Sun and not primary planets.

A long period elapsed before any new theories of importance were started, but in the 16th century of the Christian era *Copernicus* came forward and propounded his theory, which ultimately superseded all others, and is the one now (in substance) adopted. It places the Sun in the centre of the universe as the point around which all the primary planets revolve. It must not be supposed, however, that the renowned Pole attained to our existing amount of knowledge on the subject. Far from it: his

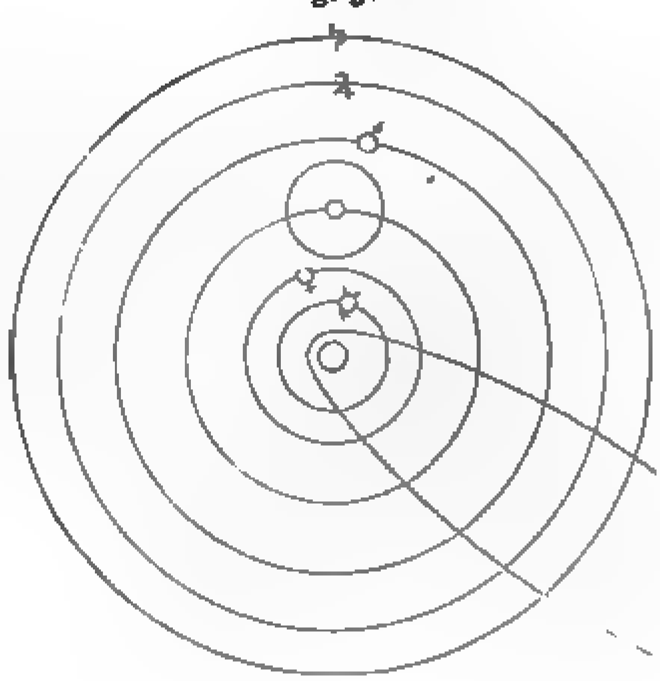
ideas were defective in more than one important particular. In order to account for the apparent irregularities in the motions of the planets, as seen from the Earth, he upheld theories which subsequent advances in the science shewed to be unnecessary and to rest on no substantial basis. Amongst other things he retained the theory of Epicycles. The ancients considered that the planetary motions must be effected uniformly and in circles, because uniform motion appeared the most perfect kind of motion, and a circle the most perfect and most noble kind of curve. There is at any rate a reverential spirit in this idea which, notwithstanding our enlightenment, we need not despise. Copernicus announced his system in a treatise entitled *De Revolutionibus Orbium cælestium*, the actual publication of which he did not live to see; for him this was perhaps fortunate rather than otherwise, because the work was condemned by the Papal "Congregation of the Index." Had it been possible for those reverend gentlemen to have got the author within their clutches, it is more than likely that he would have suffered as well as his book; as did Galileo after him.

Fig 29.



THE EGYPTIAN SYSTEM.

Fig. 30.

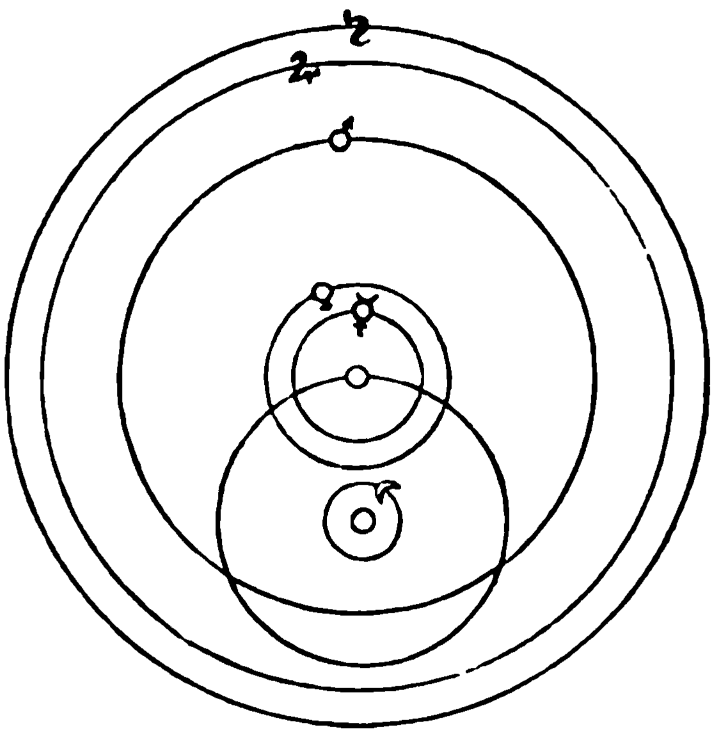


THE COPERNICAN SYSTEM.

Tycho Brahe was the last great astronomer who ventured on any original speculations in this field. Influenced either by *bonâ fide* scruples resulting from an erroneous interpretation of certain

passages in Holy Scripture, or it may be, simply by a desire to perpetuate his name, he chose to regard the Earth as immoveable, and occupying the centre of the system: the Moon as revolving immediately round the Earth: and, exterior to the Moon, the Sun doing the same thing—the various planets revolving round the latter as solar satellites.

Fig. 31.



The Tychonic System.

Kepler and Newton finally set matters right by perfecting the Copernican system, and so negativing all the others.

CHAPTER III.

VULCAN. (?)

Le Verrier's investigation of the orbit of Mercury.—Narrative of the discovery of Vulcan.—Le Verrier's interview with M. Lescarbault.—Approximate elements of Vulcan.—Concluding note.

BEFORE entering upon the story of the supposed discovery of a new planet to which this name has been given, a brief prefatory statement seems necessary.

M. Le Verrier having conducted an investigation into the theory of the orbit of Mercury, was led to the conclusion that a certain error in the assumed motion of the perihelion could only be accounted for by supposing the mass of Venus to be at least $\frac{1}{10}$ greater than was commonly imagined, or else that there existed some unknown planet or planets, situated between Mercury and the Sun, capable of producing a disturbing action. Le Verrier offered no opinion on these hypotheses, but contented himself with laying them before the scientific world in the autumn of 1859 [a].

On these views being made public, a certain M. Lescarbault, a physician at Orgères, in the Department of Eure-et-Loire, France, came forward and stated that on March 26 in that year (1859), he had observed the passage of an object across the Sun's disc which he thought might be a new planet, but which he did not like to announce as such until he had obtained a confirmatory observation; he related in writing the details of his observation, and Le Verrier determined to seek a personal interview with him.

[a] *Compt. Rend.*, vol. xlix. p. 379. 1859.

The following account of the meeting will be read with interest.

"On calling at the residence of the modest and unobtrusive medical practitioner, he refused to say who he was, but in the most abrupt manner, and in the most authoritative tone, began, 'It is then you, Sir, who pretend to have observed the intra-Mercurial planet, and who have committed the grave offence of keeping your observation secret for nine months. I warn you that I have come here with the intention of doing justice to your pretensions, and of demonstrating either that you have been dishonest or deceived. Tell me then, unequivocally, what you have seen.' The doctor then explained what he had witnessed, and entered into all the particulars regarding his discovery. On speaking of the rough method adopted to ascertain the period of the first contact, the astronomer inquired what chronometer he had been guided by, and was naturally enough somewhat surprised when the physician pulled out a huge old watch with only minute hands. It had been his faithful companion in his professional journeys, he said; but that would hardly be considered a satisfactory qualification for performing so delicate an experiment. The consequence was, that Le Verrier, evidently now beginning to conclude that the whole affair was an imposition or a delusion, exclaimed, with some warmth, 'What, with that old watch, shewing only minutes, dare you talk of estimating seconds? My suspicions are already too well founded.' To this Lescarbault replied, that he had a pendulum by which he counted seconds. This was produced, and found to consist of an ivory ball attached to a silken thread, which, being hung on a nail in the wall, is made to oscillate, and is shewn by the watch to beat very nearly seconds. Le Verrier is now puzzled to know how the number of seconds is ascertained, as there is nothing to mark them; but Lescarbault states that with him there is no difficulty whatever in this, as he is accustomed 'to feel pulses and count their pulsations,' and can with ease carry out the same principle with the pendulum. The telescope is next inspected, and pronounced satisfactory. The astronomer then asks for the original memorandum, which, after some searching, is found 'covered with grease and laudanum.' There is a mistake of four minutes on it when compared with the doctor's letter, detecting which, the *savant* declares that the observation has been falsified. An error in the watch regulated by sidereal time accounts for this. Le Verrier now wishes to know how the doctor managed to regulate his watch by sidereal time, and is shewn the small telescope by which it is accomplished. Other questions are asked, to be satisfactorily answered. The doctor's rough drafts of attempts to ascertain the distance of the planet from the Sun 'from the period of four hours which it required to describe an entire diameter' of that luminary are produced, chalked on a board. Lescarbault's method, he being short of paper, was to make his calculations on a plank, and make way for fresh ones by planing them off. Not being a mathematician, it may be remarked he had not succeeded in ascertaining the distance of the planet from the Sun.

"The end of it all was, that Le Verrier became perfectly satisfied that an intra-Mercurial planet had been really observed. He congratulated the medical practitioner upon his discovery, and left with the intention of making the facts thus obtained the subject of fresh calculations [b]."

[b] Epitomised from the *North British Review*, vol. xxxiii. pp. 1–20, August 1860. A full account will also be found in *Cosmos*, vol. xvi. pp. 22–8, 1860; see also *Cosmos*, same vol., pp. 50–6.

In March or April, 1860, it was anticipated that the planet would again pass across the Sun, which was carefully scrutinised by different observers on several successive days, but no trace of it was obtained then, and in a certain sense Lescarbault's observation continues unconfirmed. However, this proves nothing, and many are prepared to regard the existence of this planet as a *fact*, to be fully demonstrated on some future occasion.

The following approximate elements were calculated by Le Verrier from Lescarbault's rough observations:—

Longitude of ascending node	=	12° 59′
Inclination of orbit	=	12° 10′
Semi-axis major ($\oplus = 1$)	=	0·143
Daily heliocentric motion	=	18° 16′
Period	=	$19^d\ 17^h$
Mean distance	=	13,082,000 miles.
Apparent diameter of $\odot$ from Vulcan ..	=	3° 36′
Do. do. do. ($\oplus = 1$)	=	6·79
Greatest possible elongation	=	8°

The application of Kepler's third law yields, as has already been shewn, a result sufficiently consistent with the results in the cases of the other planets to demand attention ; but, as will now be seen, additional evidence can be adduced as to the reality of the discovery, much as it has been called in question.

On March 20, 1862, Mr. Lummis, of Manchester, was examining the Sun's disc, between the hours of 8 and 9 A.M., when he was struck by the appearance of a spot possessed of a rapid proper motion. He called a friend's attention to it, and both remarked its sharp *circular* form. Official duties most unfortunately interrupted him, after following it for 20^m; but he has not the slightest doubt about the matter. The apparent diameter was estimated to be about 7″, and in the 20^m it moved over about 12′ of arc. The telescope employed was $2\frac{3}{4}$ inches aperture, and was charged with a power of 80. Mr. Lummis communicated with Mr. Hind on the subject of what he had seen ; and the latter, by the aid of the diagram sent, determined that 12′ was too great an estimate of the arc traversed by the spot in the time, and that 6′ would be a nearer value [c].

Two French calculators deduced elements from Lummis's obser-

[c] *Month. Not.*, vol. xxii. p. 232. April 1862.

vations: the orbits which they obtained, though necessarily very imperfect, are fairly in accord both with each other, and with Le Verrier's earlier orbit.

The first result is adopted from Valz's elements, the second from Radau's.

			I.		II.
Longitude of ascending node	..	=	$2^\circ\ 52'$	..	—
Inclination of orbit ..	.. ..	=	$10^\circ\ 21'$	..	—
Semi-axis major (⊕ = 1·0) ..	..	=	0·132	..	0·144
Daily heliocentric motion ..	..	=	$20^\circ\ 32'$	..	$18^\circ\ 5'$
Period	..	=	$17^d\ 13^h$	..	$19^d\ 22^h$
Mean distance in miles ..	..	=	12,076,000	..	13,174,000

From the heliocentric position of the nodes, it appears that transits can only occur between March 25 and April 10 at the descending, and between September 27 and October 14 at the ascending node.

Instances are not wanting of observations of spots of a planetary character passing across the Sun which may turn out to have been transits of Vulcan[d].

On October 10, 1802, Fritsch saw a round spot pass over the Sun. In 3^m it had moved $2'$, and after a cloudy interval of 4^h had disappeared.

On October 9, 1819, Stark saw a well-defined and truly circular spot, about the size of Mercury, which he could not find again in the evening.

On October 11, 1847, Schmidt saw a small black point rapidly pass across the Sun.

On October 14, 1849, the same observer saw a dark body, about $15''$ in size, pass very rapidly from East to West before the Sun. "It was neither a bird nor an insect."

In the works whence these instances are cited, others are given; but, though suspiciously suggestive of planets, the dates do not come within the necessary limits for them to have been apparitions of Vulcan, so it is not worth while to transcribe them; but nevertheless they are interesting, and worthy of attention.

It is right here to state that M. Liais asserts that being in Brazil he was watching the Sun during the period in which Lescarbault professes to have seen the black spot, and that he is

[d] *Month. Not.*, vol. xx. p. 100. Jan. 1860; also pp. 192–4; Webb, *Celest. Objects*, p. 40.

positively certain that nothing of the kind was visible, though the telescope he employed was considerably more powerful than that of the French physician. He adds that parallax will not explain the discrepancy[e].

Though it is the fashion to repudiate the reality of Vulcan's existence, yet it is scarcely prudent to dogmatise on the subject as some have done, considering that an astronomer of Hind's experience leans to the affirmative side. He says:—

"It is a suspicious circumstance that the elements as regards the place of the node, or point of intersection of the orbit with the ecliptic, and its inclination thereto, as worked out by M. Valz of Marseilles, from the data I deduced from a diagram forwarded to me by Mr. Lummis, are strikingly similar to those founded by M. Le Verrier upon the observations, such as they were, of Dr. Lescarbault. It is true if the place of the node and inclination were precisely as given by this astronomer, the object which was seen upon the Sun's disc on the 26th of March could not have been projected upon it as early as the 20th of March. But, considering the exceedingly rough nature of the observations upon which he had to rely, perhaps no stress need be placed upon the circumstance. Now the period of revolution assigned by M. Le Verrier from the observations of 1859 was 19·70 days. Taking this as an approximate value of the true period, I find, if we suppose 57 revolutions to have been performed between the observations of Dr. Lescarbault and Mr. Lummis, there would result a period of 19·81 days. On comparing this value with the previous observations in March and in October, when the same object might have transited the Sun at the opposite node, it is found to lead to October 9, 1819, as one of the dates when the hypothetical planet should have been in conjunction with the Sun. And on this very day Canon Stark has recorded the following notable observation,—'At this time there appeared a black, well-defined nuclear spot, quite circular in form, and as large as Mercury. This spot was no more to be seen at 4·37 P.M., and I found no trace of it later on the 9th, nor on the 12th, when the sun came out again.' The exact time of this observation is not mentioned, but appears likely to have been about noon, one of Stark's usual hours for examining the solar disc. Hence I deduce a corrected period of 19·812 days."

In the communication from which this is taken[f] Hind throws out suggestions for a scrutiny of the Sun at certain dates. It must be admitted that the scrutiny took place and that no planet was found, and here the matter rests.

Notwithstanding, however, the strong negative evidence against the existence of Lescarbault's planet Vulcan, Le Verrier has quite recently (December 1874) announced that the orbit of Mercury is perturbed to an extent rendering it necessary to augment the movement of the perihelion by 31″ in a century. "The con-

[e] *Ast. Nach.*, vol. liv. No. 1281. Nov. 1, 1860.
[f] Letter in the *Times*, Oct. 19, 1872.

sequence" (he says) "is very clear. There is, without doubt, in the neighbourhood of Mercury, and between that planet and the Sun, matter hitherto unknown. Does it consist of one, or several small planets? or of asteroids, or even of cosmic dust? Theory cannot decide this point [g]."

[g] *Compt. Rend.*, vol. lxxix. p. 1424. 1874.

CHAPTER IV.

MERCURY. ☿

Period, &c.—Phases.—Physical Observations by Schröter and Sir W. Herschel.—Determination of its Mass.—When best seen.—Acquaintance of the Ancients with Mercury.—Copernicus and Mercury.—Tables of Mercury.

MERCURY is, of the old planets[a], the one nearest to the Sun, round which it revolves in $87^d\ 23^h\ 15^m\ 43{\cdot}91^s$, at a mean distance of 35,392,000 miles. The eccentricity of the orbit of Mercury amounting to 0·205, the distance may either extend to 42,665,000 miles, or fall as low as 28,119,000 miles. The apparent diameter of Mercury varies between $4{\cdot}5''$ in superior conjunction, and $12{\cdot}9''$ in inferior conjunction: at its greatest elongation it amounts to about $7''$. The real diameter is about 3050 miles. The compression, or the difference between the polar and equatorial diameter, has usually been considered to be too small to be measureable, but Dawes, in 1848, gave it at $\frac{1}{28}$.

Mercury exhibits *phases* resembling those of the Moon. At its greatest elongation (say W.) half its disc is illuminated, but as it approaches superior conjunction the breadth of the illuminated part increases, and its form becomes *gibbous*; and ultimately when in superior conjunction circular: at this point the planet is lost in the Sun's rays, and is invisible. On emerging therefrom the gibbous form is still apparent, but the gibbosity is on the

[a] In case it should be thought that these accounts of the planets are too deficient in statistical data, it may here be remarked that they are intended to be read in connexion with the tabulated statistics in the Appendix of this volume, as it has been thought for several reasons undesirable to encumber these pages with too many figures. The statistics alluded to are, in this edition, placed in the Appendix, to allow of the incorporation of the results of the Transit of Venus to the latest attainable degree of completeness.

opposite side, and diminishes day by day till the planet arrives at its greatest elongation East, when it again appears like a half-moon. Becoming more and more crescented, it approaches the inferior conjunction; and having passed this, the crescent (now on the opposite side) gradually augments until the planet again reaches its greatest Westerly elongation.

Owing to its proximity to the Sun, observations on the physical appearance of Mercury are obtained with difficulty, and are therefore open to much uncertainty. The greatest possible elongation of the planet not exceeding 27° 45′ (and it being in general less), it can never be seen free from strong sunlight[b], under which conditions it may occasionally be detected with the naked eye during $1\frac{1}{2}^{h}$ or so after sunset in the spring (E. elongation) and before sunrise in the autumn (W. elongation), shining with a pale rosy hue. With the aid of a good telescope equatorially mounted, Mercury can frequently be found in the daytime.

Mercury does not appear to have received much attention from astronomers of the present day, and the observations of Schröter, at Lilienthal, and of Sir W. Herschel, are the main sources of information. The former observer and his assistant Harding obtained what they believed to be decisive evidence of the existence of high mountains on the planet's surface: one in particular, situated in the southern hemisphere, was supposed to manifest its presence from time to time, in consequence of the southern horn, near inferior conjunction, having a truncated appearance, which it was inferred might be due to a mountain arresting the light of the Sun, and preventing it from reaching as far as the cusp theoretically extended[c]. The extent of this truncature would serve to determine the height of the mountain occasioning it, which has been set down at 10·7 miles, an elevation far exceeding, absolutely, anything we have on the Earth, and in a still more marked degree relatively, when the respective diameters of the two planets are taken into consideration. Schröter, pursuing this inquiry, announced that

[b] When Mercury's elongation is the greatest possible, the planet's position is (in England) South of the Sun, and therefore the chances of seeing it are not so good as when an elongation coincides with a more Northerly position, albeit the elongation is less considerable. The greatest possible elongation is a W. one which happens at the beginning of April. The least (17° 50′) an elongation (also W.) which happens at the end of September.

[c] This has also been seen by Noble (*Ast. Register*, vol. ii. p. 106. May 1864).

the planet rotated on its axis in $24^h\ 5^m\ 48^s$. Sir W. Herschel was unable to confirm these results either in whole or even in part. The alleged period of rotation, especially, cannot be relied on.

The phases of Mercury are noticeable, as it has sometimes been found that the breadth of the illuminated portion is less than according to calculation it should be. This does not rest on the testimony of Schröter alone, but is supported by Beer and Mädler, from an observation made on September 29, 1832.

Mercury is not known to be possessed of an atmosphere; at least, if one exists, it is too insignificant to be detected. Sir W. Herschel, contradicting Schröter and Harding, pronounced against its existence. [But see Book II, chap. on "Transits," *post.*]

Mercury is, as far as we know, attended by no satellite, and the determination of its mass is a difficult and uncertain problem. However, the small comet of Encke has furnished the means of learning something, and from considerations based on the disturbances effected in the motion of this comet by the action of Mercury, it has been calculated by Encke that the mass of the latter is $\frac{1}{4865751}$ that of the Sun. Le Verrier gives $\frac{1}{3000000}$; Littrow $\frac{1}{2025810}$; and Mädler $\frac{1}{4870333}$.

The ancients were not only acquainted with the existence of this planet[d], but were able to approximate with considerable accuracy to its period, and to the nature of its motions in the heavens. "The most ancient observation of this planet that has descended to us is dated in the year of Nabonassar 494, or 60 years after the death of Alexander the Great, on the morning of the 19th of the Egyptian month *Thoth*, answering to November 15 in the year 265 before the Christian era. The planet was observed to be distant from the right line, joining the stars called β and δ in Scorpio, one diameter of the Moon; and from the star β two diameters towards the North, and following it in Right Ascension. Claudius Ptolemy reports this and many similar observations extending to the year 134 of our era, in his great work known as the *Almagest*[e]."

We have also observations of the planet Mercury, by the Chinese astronomers, as far back as the year 118 A.D. These observations consist, for the most part, of approximations (appulses)

[d] Pliny, *Hist. Nat.*, lib. ii. cap. 7; Cicero, *De Naturâ Deorum*, lib. ii. cap. 20.
[e] Hind, *Sol. Syst.*, p. 23.

of the planet to stars. M. Le Verrier, the French astronomer, has tested many of these Chinese observations by the best modern tables of the movements of Mercury, and finds, in the greater number of cases, a very satisfactory agreement. Thus, on June 9, 118, the Chinese observed the planet to be near the cluster of stars usually termed Præsepe, in the constellation Cancer; calculation from modern theory shews that on the evening of the day mentioned Mercury was less than 1° distant from that group of stars.

"Although the extreme accuracy of observations at the present day renders it unnecessary to use these ancient positions of the planets in the determination of their orbits, they are still useful as a check upon our theory and calculations, and possess, moreover, a very high degree of interest on account of their remote antiquity [f]."

La Place says: "A long series of observations were doubtless necessary to recognise the identity of the two bodies, which were seen alternately in the morning and evening to recede from and approach the Sun; but as the one never presented itself until the other had disappeared, it was finally concluded that it was the same planet which oscillated on each side of the Sun." Arago considers that "This remark of La Place's explains why the Greeks gave to this planet the two names of Apollo, the god of the day, and Mercury, the god of the thieves, who profit by the evening to commit their misdeeds."

The Greeks gave Mercury the additional appellation of ὁ Στίλβων, 'the Sparkling One.' When astrology was in vogue, it was always looked upon as a most malignant planet, and was stigmatised as a *sidus dolosum.* From its extreme mobility chemists adopted it as the symbol for quicksilver.

It is rather difficult, in a general way, to see Mercury, and Copernicus, who died at the age of 70, complained in his last moments that, much as he had tried, he had never succeeded in detecting it; a failure due, as Gassendi supposes, to the vapours prevailing near the horizon on the banks of the Vistula where the illustrious philosopher lived. An old English writer, of the name of Goad, in 1686, humorously termed this planet "a squirting

[f] Hind, *Sol. Syst.*, p 23.

lacquey of the Sun, who seldom shews his head in these parts, as if he were in debt."

In computing the places of Mercury, the Tables of Baron De Lindenau, published in 1813, were long employed, but they are now superseded by the more accurate Tables of Le Verrier[g].

[g] *Annales de l'Obs. de Paris*, 1859.

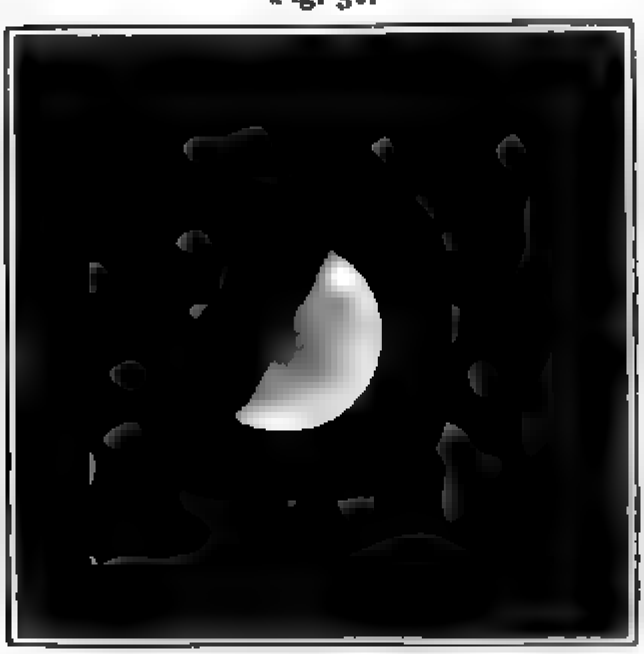
CHAPTER V.

VENUS. ♀

Period, &c.—Phases resemble those of Mercury.—Most favourably placed for observations once in eight years.—Daylight observations.—Its brilliancy.—Its Spots and Axial Rotation.—Suspected mountains and atmosphere.—Its "ashy light."—Phase irregularities.—Suspected Satellite.—Observations on it.—The Mass of Venus.—Ancient observations.—Galileo's anagram.—Venus useful for nautical observations.—Tables of Venus.

NEXT in order of distance from the Sun, after Mercury, is Venus; which revolves round the Sun in $224^{d}\ 16^{h}\ 49^{m}\ 8^{s}$, at a mean distance of 66,131,000 miles. The eccentricity of the orbit of Venus amounting to only 0·006, the extremes of distance are only 66,585,000 miles and 65,677,000 miles. This eccentricity is very small. No planet, major or minor, has an eccentricity so small. The apparent diameter of Venus varies between 9·7″ in superior and 66·5″ in inferior conjunction. At its greatest elongation its apparent diameter is about 25″. A numerous series of careful observations enabled Main to determine that the planet's diameter (reduced to mean distance) is 17·55″, subject to a correction of −0·5″ for the effects of irradiation. Stone, from an elaborate discussion of a large series of Greenwich observations, obtained 16·944″, with a probable error

Fig. 32.



Venus near its Greatest Elongation. (*Schröter.*)

of $\pm 0{\cdot}08''$. Tennant in 1874 (during the Transit) obtained, as the mean of 68 measures. $16{\cdot}9036''$ (reduced) with a probable error of $0{\cdot}0016''$ only [a]. The real diameter corresponding to this latter evaluation is about 7500 miles, or, roundly, Venus's diameter is almost the same as the Earth's. The compression must be small, but Tennant thinks he found traces thereof. Great difficulty must ever arise in clearly detecting it, because the planet's diameter in superior conjunction is so small.

Venus exhibits phases precisely identical with those of Mercury.

Though under the most favourable circumstances Venus is never farther removed from the Sun than 47° 15′, and is therefore always more or less under the influence of twilight, yet it is difficult to scrutinise this planet for a reason additional to that which obtains with Mercury, namely, its own extreme brilliancy. This is such as to render the planet not unfrequently visible in full daylight and capable of casting a sensible shadow at night. This happened in Jan. 1870, and occurs every 8 years, when the planet is at or near its greatest North latitude and about 5 weeks from inferior conjunction. Its apparent diameter is then about 40″, and the breadth of the illuminated part nearly 10″, so that rather less than $\frac{1}{4}$th of the entire disc is illuminated, but this fraction transmits more light than do phases of greater extent, because the latter correspond to greater distances from the Earth. A lesser maximum of brilliancy, due to the same circumstances less favourably carried out, occurs on either side of the Sun at intervals of about 29 months. The planet's angular distance from the Sun on these occasions is rather less than 40° (in the superior part of its orbit); so its phase therefore corresponds with that of the Moon 11^d and 17^d old.

Fig. 33.

VENUS NEAR ITS INFERIOR CONJUNCTION.
(*Schröter.*)

Observations of Venus in the daytime were first made at a very early period; the following are the dates of a few instances: 398,

[a] *Month. Not.*, vol. xxxv. p. 347. May 1875.

984, 1008, 1014, 1077, 1280, 1363, 1715, 1750. "Bouvard has related to me," says Arago, "that General Buonaparte, upon repairing to the Luxembourg, when the Directory was about to give him a fête, was very much surprised at seeing the multitude which was collected in the Rue de Tournon pay more attention to the region of the heavens situate above the palace than to his person or to the brilliant staff which accompanied him. He inquired the cause, and learned that these curious persons were observing with astonishment, although it was noon, a star, which they supposed to be that of the conqueror of Italy; an allusion to which the illustrious general did not seem indifferent when he himself with his piercing eyes remarked the radiant body. The star in question was no other than Venus [b]."

The dazzling brilliancy of this planet is such [c] that the daytime is to be preferred for observing it, but under the best of circumstances it is far too tremulous for physical observations to be conveniently made. J. D. Cassini attacked it in 1667, and some ill-defined dusky spots seen on various occasions during April, May, and June, enabled him to assign $23^h\ 16^m$ for its axial rotation. Bianchini, in 1726 and 1727, favoured by an Italian sky, observed spots with greater facility: thence he inferred a rotation performed in 24 *days* 8 hours. Sir William Herschel, desirous of arriving at some more decisive conclusion, devoted much care to the inquiry; but he was unable to assign a precise period beyond generally believing that Bianchini's statement was largely in excess of the true amount. Schröter, by close attention to certain spots, deduced a period of $23^h\ 21^m\ 7{\cdot}98^s$, which Di Vico and his colleagues at Rome, in 1840–2, only slightly modified to $23^h\ 21^m\ 23{\cdot}93^s$. We may thus assume that the period of the axial rotation of this planet is known to within a very small fraction of the whole amount.

Sir W. Herschel's opinion of the spots which he saw was that they were in an atmosphere, and did not belong to the solid body —an opinion supported by no analogy, and now, with reason, believed to be groundless, for Di Vico found the spots just as delineated by Bianchini. The Roman observers, 6 in number, displayed great diligence in the matter, and Bianchini's drawings were,

[b] *Pop. Ast.*, vol. i. p. 701, English edition.

[c] Denison states that Venus has been experimentally found to be 10 times as bright as the brightest part of the full moon. (*Ast.*, p. 149, 3rd ed.)

with one exception, confirmed. Of the 6 observers, the most successful were those who had most difficulty in catching very minute companions to large stars, the reason of which Webb points out to be obvious enough. A very sensitive eye, which would detect the spots readily, would be easily overpowered by the light of a brilliant star, so as to miss a very minute one in its neighbourhood.

Mountains probably exist on Venus, though the testimony on which the statement must rest is not quite so conclusive as could be desired. In August 1700 La Hire, observing the planet in the daytime near its inferior conjunction, perceived in the lower region of the crescent inequalities which could only be produced by mountains higher than those in the Moon. To the same effect Derham, writing in 1715. Schröter asserted[d] the existence of several high mountains, in which he was confirmed by Beer and Mädler, but his details as to precise elevation measured by toises must be accepted with great reserve, amongst other reasons because it is doubtful whether his micrometers were of sufficient delicacy. Sir W. Herschel disbelieved him on some points, and attacked him in the *Philosophical Transactions* for 1793[e]: his reply was published in the volume for the year but one after[f]; it was calm and dignified, and vindicated the mountains if not the measurements. Di Vico, at Rome, in April and May 1841, appears to have noticed a surface-configuration akin to that of the Moon; and Lassell, when at Malta in January 1862, observed the same sort of thing. Browning, on March 14, 1868, saw mottlings on the surface of Venus which reminded him of the look of the Moon as seen in a small telescope through a mist. A bluntness of the southern horn, referred to by Schröter, was also seen by the Roman astronomers, and often by Breen subsequently with the Northumberland telescope at Cambridge.

That Venus has an atmosphere is generally admitted; that it is of considerable density is likewise an opinion apparently well founded. During the transits of 1761, 1769, and 1874, the planet was observed by several persons to be surrounded by a faint ring of light, such as an atmosphere would account for. Schröter, too, discovered what appeared to him to be a faint crepuscular light

d *Phil. Trans.*, vol. lxxxii. p. 337. 1792.

e *Phil. Trans.*, vol. lxxxiii. p. 202. 1793.

f *Phil. Trans.*, vol. lxxxv. p. 117. 1795.

extending beyond the cusps of the planet into the dark hemisphere. From micrometrical measures of the space over which this light was diffused he considered the horizontal refraction at the surface of the planet to amount to 30′ 34″, or much the same as that of the Earth's atmosphere. Sir W. Herschel confirmed the discovery as a whole[g], and more recently Mädler was able to do the same with the mere modification of making the amount somewhat greater, or equal to 43·7′. With this the 1874 Transit results fairly agree.

The existence of snow at the poles of Venus has been suspected by Webb and Phillips, but the idea awaits confirmation, though there is no *primâ facie* reason why it should not be well founded; indeed rather the reverse.

A phenomenon analogous to the *lumière cendrée*, or 'ashy light,' of the Moon is well attested in observations of Venus when near inferior conjunction. Many observers have noticed the entire contour of the planet to be of a dull grey hue beyond the Sun-illumined crescent. Webb uses the expression *the phosphorescence of the dark side:* I cannot but regard this as an objectionable phrase, for phosphorescence notably conveys the idea that some *inherent* light is spoken of, whereas there can be little doubt that reflection is in some way or other the cause of what is seen in the case of Venus, though it may be difficult at present to specify the precise nature of it[h]. Derham noticed this appearance, and refers to it in his book; and Schröter, Sir W. Herschel, Di Vico, and Guthrie[i] are amongst those that have seen it. The chief objection however to the term *phosphorescence* lies in the fact that Green, Winnecke, Noble, and several others have repeatedly seen the un-illuminated limb of Venus distinctly *darker* than the back-ground on which it was projected.

The peculiarity about Mercury's phases already pointed out (the measured breadth being different from the calculated) obtains also with Venus. At the greatest elongations, the line terminating the illumination ought to be straight, as with a half-moon, but several observers have found a discrepancy of between 3^d and 8^d between the first, or last, appearance of the *dichotomisation* (according as one or other elongation was referred to). Thus, at the Westerly

[g] *Phil. Trans.*, vol. lxxxiii. p. 214. 1793.

[h] The supposition of the existence of some such phenomenon as our Aurora Borealis seems a rather poor hypothesis.

[i] *Month. Not.*, vol. xiv. p. 169. March 1854.

elongation of August 1793, Schröter found the terminator slightly concave, and it did not become straight till 8^d after the epoch of greatest elongation.

Previous to the present century testimony was not wanting that Venus had a satellite, but nothing has been ascertained about it in recent times, and Webb, with great propriety, calls the matter "an astronomical enigma." On Jan. 25, 1672, J. D. Cassini saw, between $6^h\ 52^m$ and $7^h\ 2^m$ A.M., a small star resembling a crescent, like Venus, distant from the Southern horn on the Western side by a space equal to the diameter of Venus. On Aug. 28, 1686, at $4^h\ 15^m$ A.M., the same experienced observer saw a crescent-shaped light East of the planet at a distance of $\frac{3}{5}$ths of its diameter. Daylight rendered it invisible after $\frac{1}{4}$ an hour. On Oct. 23, 1740 (O.S.), Short, the celebrated optician, with 2 telescopes and 4 different powers, saw a small star perfectly defined but less luminous than the planet, from which it was distant $10'\ 2''$. On 4 different occasions between May 3 and 11, 1761, Montaigne, at Limoges, saw what he believed to be a satellite of Venus. It presented the same phase as the planet, but it was not so bright. Its position varied, but its diameter appeared equal to $\frac{1}{4}$th that of the planet. The following extract is from the *Dictionnaire de Physique*, a French work published in 1789. "The year 1761 will be celebrated in astronomy in consequence of the discovery that was made on May 3 of a satellite circulating round Venus. We owe it to M. Montaigne, member of the Society of Limoges, who observed the satellite again on the 4th and 7th of the same month. M. Baudouin read before the Academy of Sciences of Paris a very interesting memoir, in which he gave a determination of the revolution and distance of the said satellite. From the calculations of this expert astronomer we learn that the new star has a diameter about $\frac{1}{4}$th that of Venus, that it is distant from Venus almost as far as the Moon is from the Earth, that its period is $9^d\ 7^h$, and that its ascending node is in the 22nd degree of Virgo." Wonderfully circumstantial! In March 1764 several European observers, at places widely apart, saw a supposed satellite. Rödkier, at Copenhagen, on March 3 and 4, saw it: Horrebow, with some friends, also at Copenhagen, saw it on the 10th and 11th of the same month, and they stated that they took various precautions to make sure there was no optical illusion. Montbaron, at Auxerre,

on March 15, 28, and 29, saw the satellite in sensibly different positions [j].

This is the plaintiff's case, if I may be pardoned for using such an expression: on the other side it can only be said that no trace of a satellite has ever been seen by any subsequent observer with larger telescopes. And with the care bestowed on Venus by Sir W. Herschel and Schröter during so many years, it is difficult to understand that, if it existed, they should not have seen it at some time or other.

Lambert combined all the observations in a very tolerable orbit[k], but, as Hind points out[l], notwithstanding its agreement with the observations, there is one fatal objection to it—if it were correct, the mass of Venus would be 10 times greater than what other methods shew it to be, namely $\frac{1}{401211}$ that of the Sun. Encke gives $\frac{1}{401839}$, Littrow $\frac{1}{405871}$, Mädler $\frac{1}{401718}$, and Le Verrier $\frac{1}{412150}$. There are several methods of ascertaining this quantity, the most obvious of which is based on the disturbing influence exerted by Venus on the Earth's annual motion.

Venus has ever been regarded as an interesting and popular planet, and it is somewhat remarkable that it is the only one whose praises are sung by the great Greek bard, who thus apostrophises it:—

"Ἕσπερος, ὃς κάλλιστος ἐν οὐρανῷ ἵσταται ἀστήρ[m]."

This refers to it as the Evening Star, but elsewhere in the Iliad[n] we meet with it in its other function of the Ἑωσφόρος, to which the Latin *Lucifer* corresponds. Some have thought, and perhaps not without reason, that it is the object referred to in *Isaiah* xiv. 12.

The earliest recorded observations of Venus date from 685 B.C. (Ast)., and appear on an earthenware tablet now in the British Museum[o].

"Claudius Ptolemy has preserved for us in his *Almagest* many observations of Venus by himself and other astronomers before him, at Alexandria in Egypt. The most ancient of these observations is dated in the 476th year of Nabonassar's era and 13th of

[j] Scheuten says he saw a satellite accompany Venus across the Sun during the transit of 1761. See *Ast. Jahrbuch*, 1778.

[k] Bode's *Jahrbuch*, 1777.

[l] *Sol. Syst.*, p. 27.

[m] Homer, *Iliad*, lib. xxii. v. 318.

[n] Lib. xxiii. v. 226. Pythagoras (or, according to others, Parmenides) determined the identity of the two "stars."

[o] *Month. Not.*, vol. xx. p. 319. June 1860.

the reign of Ptolemy Philadelphus, on the night of the 17th of the Egyptian month *Messori*, when Timocharis saw the planet eclipse a star at the extremity of the wing of Virgo. This date answers to 271 B.C., Oct. 12 A.M.[p]" As this was not a telescopic observation, it and all others recorded before telescopes came into use are open to this uncertainty, that the two objects may merely have been in juxta-position so as to have appeared as one without actual *super*-position taking place. The recorded occultation of Mercury by Venus on May 17, 1737, was no doubt an occultation in the strict sense of the word.

The interesting discovery of the phases of Venus is due to Galileo[q], who announced the fact to his friend Kepler in the following logograph, or anagram[r]:—

"Hæc immatura, a me, jam frustra, leguntur.—oy."

"These things not ripe [for disclosure] are read, as yet in vain, by me."

Or, as another interpretation has it—

"These things not ripe; at present [read] in vain [by others] are read by me."

The "me" in the former case being the ordinary reader; in the latter, Galileo. This, when transposed, becomes—

"Cynthiæ figuras æmulatur Mater Amorum."

"The Mother of Love [Venus] imitates the phases of Cynthia [the Moon]."

To the mariner, owing to its rapid motion, Venus is a useful auxiliary for taking lunar distances when continuous bad weather may have prevented observations of the Sun.

In computing the places of Venus the tables of Baron De Lindenau, published in 1810, were long in use, but they have now been superseded by those of Le Verrier, for amongst other causes of error there existed a long inequality (discovered by Sir G. B. Airy in 1846) affecting the heliocentric places of the Earth and the planet to a very sensible amount. This inequality goes through all its changes in about 239y, and when at a maximum displaces Venus by 3″ and the Earth by 2″, as viewed from the Sun.

p Hind, *Sol. Syst.*, p. 32.

q It was one of the objections urged to Copernicus against his theory of the solar system that if it were true then the inferior planets ought to exhibit phases. He is said to have answered that if ever men obtained the power of seeing them more distinctly, they would be found to do so. Prof. De Morgan believes the anecdote to be apocryphal. (*Month. Not.*, vol. vii. p. 290. June 1847.) But "se non è vero, è ben trovato."

r *Opere di Galileo*, vol. ii. p. 42. Ed. Padova, 1744.

CHAPTER VI.

THE EARTH. ⊕

"O let the Earth bless the Lord: yea, let it praise Him, and magnify Him for ever."—*Benedicite.*

Period, &c.—Figure of the Earth.—The Ecliptic.—The Equinoxes.—The Solstices.—Diminution of the obliquity of the ecliptic.—The eccentricity of the Earth's orbit.—Motion of the Line of Apsides.—Familiar proofs and illustrations of the sphericity of the Earth.—Mädler's tables of the duration of day and night on the Earth.—Opinion of ancient philosophers.—English mediæval synonyms.—The Zodiac.—Mass of the Earth.

THE Earth is a planet in all essential respects similar to Venus and Mars, its nearest neighbours; but as we are on it, it is needless to point out the impossibility of treating of it in the same way as we treat of the other planets. It revolves round the Sun in $365^d\ 6^h\ 9^m\ 9{\cdot}6^s$, at a mean distance of 91,430,000 miles. The eccentricity of its orbit amounting to 0·016, this distance may either extend to 92,965,000 miles or contract to 89,895,000 miles; and these differences involve variations in the light and heat reaching the Earth which will be represented by the figures 966 and 1033, the mean amount being 1000.

The Earth is not a sphere, but an oblate spheroid (that is to say, it is somewhat flattened at the poles and protuberant at the equator); like many and probably all of the planets. The following table gives the latest authentic measurements.

	Airy[a].	Bessel[b].
	Miles.	Miles.
Polar Diameter	7899·170	7899·114
Equatorial Diameter..	7925·648	7925·604
Absolute Difference	26·478	26·490
Excess of the Equatorial, expressed as a fraction of the entire length	$\frac{1}{299·330}$	$\frac{1}{299·152}$

The close coincidence between these results supplies a good guarantee of the accuracy of both, and is noticeable as an illustration of the precision arrived at in the working out of such problems, the difference between the two values of the equatorial diameter being only 77 yards. If we represent the Earth by a sphere 1 yard in diameter that diameter will make the polar diameter $\frac{1}{8}$ inch too long.

Further, it has been recently suspected by General Schubert and Colonel A. R. Clarke that the equatorial section of the Earth is not circular, but elliptical. Colonel Clarke's conclusion is that the equatorial diameter, which pierces the Earth through the meridians 13° 58′ and 193° 58′ E. of Greenwich, is 1 mile longer than the diameter at right angles to it[c].

A consideration of the method in which such investigations are conducted does not fall within the scope of the present sketch, but in Airy's *Astronomy* the subject of the Figure of the Earth is handled with much clearness[d].

The great circle of the heavens *apparently* described by the Sun every year (owing to our revolution round that body) is called the *ecliptic*[e], and its plane is usually employed by astronomers as a fixed plane of reference. The plane of the Earth's equator, extended towards the stars, marks out the equator of the heavens, the plane of which is inclined to the ecliptic at an angle which, on Jan. 1, 1875, amounted to 23° 27′ 19·93″; this angle is known as the *obliquity of the ecliptic*. It is this inclination which gives rise to the vicissitudes of the seasons during our annual journey round the Sun. The two points where the celestial equator intersects

[a] *Encycl. Metrop.*, art. *Fig. of Earth.*
[b] *Ast. Nach.*, vol. xiv. Nos. 333-5; vol. xix. No. 438.
[c] *Mem. R.A.S.*, vol. xxix. p. 39. 1861.
[d] See p. 242 *et seq.*
[e] "The line of eclipses."

the ecliptic are called the *equinoxes*[f]; the points midway between these being the *solstices*[g]. It is from the vernal (or spring) equinox that Right Ascensions are measured along the equator, and Longitudes along the ecliptic. The obliquity of the ecliptic is now slowly decreasing at the rate of about 48″ in 100 years. "It will not always, however, be on the decrease; for before it can have altered 1½° the cause which produces this diminution must act in a contrary direction, and thus tend to increase the obliquity. Consequently the change of obliquity is a phenomenon in which we are concerned only as astronomers, since it can never become sufficiently great to produce any sensible alteration of climate on the Earth's surface. A consideration of this remarkable astronomical fact cannot but remind us of the promise made to man after the Deluge, that 'while the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease.' The perturbation of obliquity consisting merely of an oscillatory motion of the plane of the ecliptic, which will not permit of its [inclination] ever becoming very great or very small, is an astronomical discovery in perfect unison with the declaration made to Noah, and explains how effectually the Creator had ordained the means for carrying out His promise, though the way it was to be accomplished remained a hidden secret until the great discoveries of modern science placed it within human comprehension[h]."

It is stated by Pliny that the discovery of the obliquity of the ecliptic is due to Anaximander, a disciple of Thales, who was born in 610 B.C. Other authorities ascribe it to Pythagoras or the Egyptians, while Laplace believes that observations for the determination of this angle were made by Tcheou-Kong in China not less than 1100 years before the Christian era[i]. The accord between the various determinations ancient and modern is very remarkable, and indicates the great care bestowed by the astronomers of antiquity on their work.

[f] From *æquus* equal, and *nox* a night; because when the Sun is at these points, day and night are theoretically equal throughout the world. In 1875 this occurred on March 20 at 12^h, and Sept. 22 at 23^h, G.M.T.

[g] From *sol* the Sun, and *stare* to stand still; because the Sun when it has reached these neutral points has attained its greatest declination N. or S. as the case may be. In 1875 this occurred on June 21 at 9^h, and Dec. 21 at 17^h, G.M.T.

[h] Hind, *Sol. Syst.*, p. 33.

[i] *Conn. des Temps.* 1811.

The eccentricity of the Earth's orbit amounts (to be more precise than above) to 0·0167917, and it is subject to a very small diminution, not exceeding 0·000041 in a period of 100 years. Supposing the change to go on continuously, the Earth's orbit must eventually become circular; but we are enabled to prove by the theory of attraction that this progressive diminution is only to proceed for a certain time. Le Verrier has shewn that this diminution cannot continue beyond 24,000 years, when the eccentricity will be at its minimum of ·0033: it will then begin to increase again; so that unless some external cause of perturbation arise, these variations must continue throughout all ages, within certain not very wide limits. They are due to the attractive influence of the Planets. The above value of the eccentricity is for 1800·0 A.D.

The line of apsides is subject to an annual direct change of 11·77″, independent of the effects of precession (to be described hereafter); so that, allowing for the latter cause of disturbance, the annual movement of the apsides may be taken as rather more than 1′. One important consequence of this motion of the major axis of the Earth's orbit is the variation in the lengths of the seasons at different periods of time. In the year 3958 B.C., or, singularly enough, near the epoch of the Creation of Adam, the longitude of the Sun's perigee coincided with the autumnal equinox; so that the summer and autumn quarters were of equal length, but shorter than the winter and spring quarters, which were also equal. In the year 1267 A.D. the perigee coincided with the winter solstice; the spring quarter was therefore equal to the summer one, and the autumn quarter to the winter one, the former being the longest. In the year 6493 A.D. the perigee will have completed half a revolution, and will then coincide with the vernal equinox; summer will then be equal to autumn, and winter to spring; the former seasons, however, being the longest. In the year 11719 A.D. the perigee will have completed three-fourths of a revolution, and will then coincide with the summer solstice; autumn will then be equal to winter, but longer than spring and summer, which will also be equal. And finally in the year 16945 A.D. the cycle will be completed by the coincidence of the solar perigee with the autumnal equinox. This motion of the apsides of the Earth's orbit, in connection with the inclination of its axis to the plane of it, must quite obviously have

been the cause of very remarkable vicissitudes of climate in pre-Adamite times[k].

One result of this position of things we may readily grasp at this moment. As a matter of fact, in consequence of our seasons being now of unequal length, the spring and summer quarters jointly extend to 186^{d}, whilst the autumn and winter quarters only comprise 178^{d}. The sun is therefore a longer time in the Northern hemisphere than in the Southern hemisphere: hence the Northern is the warmer of the two hemispheres. Probably it may be taken as an incidental proof of this fact that the North Polar regions of the Earth are easier of access than the South Polar regions. In the Northern hemisphere navigators have reached to 81° of latitude, whereas 71° is the highest attained in the Southern hemisphere.

It is not a very easy matter in treating of the Earth to determine where astronomy ends and geography begins; but a brief allusion to the means available for deciding the form of the Earth seems all that it is now necessary to add. We learn that the Earth is a sphere (or something of the sort) by the appearance presented by a ship in receding from the spectator: first the hull disappears, then the lower parts of the rigging, and finally the top-masts. The shadow cast on the Moon during a lunar eclipse, and the varying appearances of the constellations as we proceed northwards or southwards, are amongst the other more obvious indications of the Earth's globular form.

The following table of the greatest possible length of the day in different latitudes I cite from Mädler[1]:—

°	′	Hours.	°	′	Hours.
0	0	12	65	48	22
16	44	13	66	21	23
30	48	14	66	32	24
41	24	15	67	23	1 month.
49	2	16	69	51	2 „
54	31	17	73	40	3 „
58	27	18	78	11	4 „
61	19	19	84	5	5 „
63	23	20	90	0	6 „
64	50	21			

[k] See Papers by Croll, *Phil. Mag.*, 4th Ser., vol. xxxv. p. 363. May 1868; vol. xxxvi. pp. 141 and 362. Aug. and Nov. 1868; Geikie's *Great Ice Age*, &c.

[1] *Pop. Ast.*, p. 30.

The 8646 hours which, according to Mädler, make up a year, are thus distributed :—

At the Equator.			At the Poles.		
4348	hours	Day,	4389	hours	Day,
852	„	Twilight,	2370	„	Twilight,
3446	„	Night.	1887	„	Night.

Among the ancients, Aristarchus of Samos and Philolaüs maintained that not only did our globe rotate on its own axis, but that it revolved round the sun in 12 months[m]. Nicetas of Syracuse is also mentioned as a supporter of this doctrine[n]. The Egyptians taught the revolution of Mercury around the Sun[o]; and Apollonius Pergæus assigned a similar motion to Mars, Jupiter, and Saturn—but I am digressing. Hesiod states that the Earth is situated exactly half-way between Heaven and Tartarus[p]. Our ancestors 300 or 400 years ago termed the ecliptic the "thwart circle;" the meridian, the "noonsteede circle;" the equinoxial, "the girdle of the sky;" the Zodiac, "the Bestiary," and "our Lady's waye." The origin of the division of the zodiac into constellations is lost in obscurity. Though commonly attributed to the Greeks, it now seems certain that the custom is of much earlier date; and is possibly due to the ancient Hindùs or the Chinese, in whose behalf, however, a claim to prior knowledge is always put in, whenever we Europeans fancy that we have made a discovery.

The following are recent values of the mass of the Earth compared with that of the Sun:—Encke $\frac{1}{359551}$, Littrow $\frac{1}{355000}$, Mädler $\frac{1}{355499}$, and Le Verrier $\frac{1}{354030}$. Le Verrier, however, once seemed to consider that these values were all too small, but that in our state of uncertainty as to the Sun's parallax it was not possible to assign with confidence a definitive value[q].

m Archimedes, *In Arenario;* Plutarch, *De Placit. Philos.*, lib. ii. cap. 24; Diog. Laërt. *In Philolao.*

n Cicero, *Acad. Quæst.*, lib. ii. cap. 39.

o Macrobius, *Comment. in Somn. Scip.*, lib. i. cap. 19, and others.

p "From the high heaven a brazen anvil cast,
Nine days and nights in rapid whirls would last,
And reach the Earth the tenth; whence strongly hurl'd,
The same the passage to th' infernal world."
HESIOD, *Theogonia*, ver. 721.

q See *Month. Not.*, vol. xxxii. pp. 302 and 323. 1872.

CHAPTER VII.

THE MOON. ☾

Period, &c.—Its Phases.—Its motions and their complexity.—Libration.—Evection.—Variation.—Parallactic inequality.—Annual equation.—Secular acceleration.—Diversified character of the Moon's surface.—Lunar mountains.—Seas.—Craters.—Volcanic character of the Moon.—Lunar atmosphere.—Researches of Schröter, &c.—Hansen's curious speculation.—The Earth-shine.—The Harvest Moon.—Astronomy to an observer on the Moon.—Luminosity and calorific rays.—Historical notices as to the progress of Lunar Chartography.

THE Moon, as the Earth's satellite, is to us the most important of the "secondary planets," and will therefore receive a somewhat detailed notice.

The Moon revolves round the Earth in $27^d\ 7^h\ 43^m\ 11{\cdot}461^s$, at a mean distance of 238,830 miles. The eccentricity of its orbit amounting to 0·0549, the Moon may recede from the Earth to a distance of 251,900 miles, or approach it to within 225,700 miles. Its apparent diameter[a] varies between 29′ 21″ and 33′ 31″. The diameter at mean distance is 31′ 5″. It will fix this in the memory to note that the apparent diameter is the same as the Sun's, and equals ½°. The real diameter, according to Mädler, is 2159·6; according to Wichmann 2162 miles. Recent researches shew that these values are too great; and that a correction of about 2″ (Airy) or 2·15″ (De La Rue) must be applied to the measured visual diameter of the Moon, to allow for the exaggeration of its dimensions by irradiation. This reduction amounts to about 2 miles. The most delicate measurements indicate no compression.

The Moon has phases like the inferior planets, and of the various influences ascribed to it that which results in the tides of the

[a] These figures must be regarded as geometrically rather than practically true, for under varying circumstances of altitude above the horizon the diameter of the Moon will be found to vary considerably. And the diameter at mean distance is not the arithmetic mean of the extremes of apparent diameter.

ocean is the most important, and will hereafter be treated at some length.

The motions of the Moon are of a very complex character: they have largely occupied the attention of astronomers during all ages, and they can only be said to have been mastered within a recent period.

Speaking roughly, we may say that the same hemisphere of the Moon is always turned towards us; but although this is, in the main, correct, yet there are certain small variations at the edge which it is necessary to notice. The Moon's axis, although nearly, is not exactly perpendicular to the plane of its orbit, deviating therefrom by an angle of 1° 32′ 9″ (Wichmann); owing to this fact, and to the inclination of the plane of the lunar orbit to that of the ecliptic, the poles of the Moon lean alternately to and from the Earth. When the North pole leans towards the Earth we see somewhat more of the region surrounding it, and somewhat less when it leans the contrary way; this is known as *libration in latitude*[b]. The extent of the displacement in this direction is 6° 47′. In order that the same hemisphere should be continually turned towards us, it would be necessary not only that the time of the Moon's rotation on its axis should be precisely equal to the time of its revolution in its orbit, but that its angular velocity in its orbit should, in every part of its course, exactly equal its angular velocity on its axis. This, however, is not the case, for its angular velocity in its orbit is subject to a slight variation, and in consequence of this a little more of its Eastern or Western edge is seen at one time than another; this phenomenon is known as the *libration in longitude*, and was discovered by Hevelius, who described it in 1647[c]. The extent of the displacement in longitude is 7° 53′. The maximum total libration (as viewed from the Earth's centre) amounts to 10° 24′. On account of the diurnal rotation of the Earth, we view the Moon under somewhat different circumstances at its rising and at its setting, according to the latitude of the Earth in which we are placed. By thus viewing it in different positions, we see it under different aspects; this gives rise to another phenomenon, the *diurnal libration*, but the maximum value of this is only 1° 1′ 24″.

[b] *Librans*, balancing.

[c] *Selenographia.*

This periodical variation in the visible portion of the Moon's disc seems to have been first remarked by Galileo—a discovery very creditable to him when we consider the inefficient materials with which he worked. According to Arago, the various librations enable us to see altogether $\frac{57}{100}$ of the Moon's surface, the portion always invisible amounting only to $\frac{43}{100}$ of the same.

The following account of the chief perturbations in the motion of the Moon is, in the main, abridged from that invaluable repertory of astronomical facts, Hind's *Solar System*.

1. The *Evection* depends on the angular distance of the Moon from the Sun, and on the mean anomaly of the former. It diminishes the equation of the centre in the syzygies and increases it in the quadratures, increasing or diminishing the Moon's mean longitude by $1° 20' 29{\cdot}9''$. Period, about $31^d 19^h 30^m$. Discovered by Ptolemy, but previously suspected by Hipparchus.

2. The *Variation* depends solely on the angular distance of the Moon from the Sun. Its effect is greatest at the octants, and disappears in the syzygies and quadratures, the longitude of the Moon being altered thereby $35' 41{\cdot}6''$ when at a maximum. Period, half a synodical revolution, or about $14^d 18^h$. Its discovery is usually ascribed to Tycho Brahe, but Sedillot and others claim it for Abụl Wefa, who lived in the 9th century. It was the first lunar inequality explained by Sir I. Newton on the theory of gravitation.

3. The *Parallactic Inequality* arises from the sensible difference in the disturbing influence exerted by the Sun on the Moon, according as the latter is in that part of its orbit nearest to, or most removed from, the Sun. At its maximum it alters the Moon's longitude by about $2'$. Period, one synodical revolution, or $29^d 12^h 44^m$.

4. The *Annual Equation* is that inequality in the Moon's motion, which results from the variation in the velocity of the Earth, caused by the eccentricity of its orbit. At its maximum the Moon's longitude is altered by $11' 11{\cdot}97''$. Period, one anomalistic solar year, or $365^d 6^h 13^m 49{\cdot}3^s$.

5. The *Secular Acceleration* of the Moon's mean motion had been supposed to be caused wholly by the diminution in the eccentricity of the Earth's orbit which has been going on for many centuries, as has already been pointed out; but in 1853 it was shewn by

Professor Adams that the amount of this acceleration is just double that which such diminution *per se* would account for. At present the mean motion of the Moon is being increased at the rate of about 12″ every 100 years. This inequality was detected by Halley in 1693 from a comparison of the periodic time of the Moon, deduced from Chaldæan observations of eclipses, made at Babylon in the years 720 and 719 B.C., and Arabian observations made in the 8th and 9th centuries A.D. Laplace first reasoned out and explained the theory of the inequality, and up to the date of Adams's researches his calculations were supposed to be complete. It was, however, shewn by our great geometer that Laplace had neglected certain quantities in his calculations, and so estimated the accelerating effect of the increase of the minor axis of the Earth's orbit at double its true amount. It has been suggested by Delaunay and others that half of this seeming acceleration has its origin in the real increase in length of our terrestrial day, which has actually lengthened and continues to lengthen by a small fraction of a second annually; and this slower rotation of the Earth (for that is what it amounts to) is conceived to have its origin in the friction of the tides, which act as a break on the Earth rotating beneath them.

Hansen elucidated, a few years ago, two other inequalities in the Moon's motion, due, the one directly and the other indirectly, to the influence of Venus [d]; and it was hoped that when these were taken into account it would have been found possible to say that the position of the Moon deduced from theory is almost precisely the same as that obtained by direct observation, and therefore that our knowledge of the Moon's motion is almost perfect, but further research by Sir G. B. Airy has cast a doubt on the matter.

When viewed by the naked eye the Moon presents a mottled appearance; this arises from our satellite being unequally reflective, a fact which the telescope teaches us to be due to numerous mountains and valleys on its surface, as was discovered by Galileo. The proof of the existence of these is found in the shadows cast by the high peaks on the surrounding plains, when the Sun shines obliquely; these shadows disappear, however, at the full phase, as the Sun

[d] The statement in the text is not quite correct, so far that in the case of one of these inequalities (the 239-year one) what Hansen did was to trace the operation on the Moon of that influence of Venus which Airy connected only with the Earth. The second of these Hansen inequalities runs its course in 273 years. See on the whole subject a paper by Airy in *Month. Not.*, vol. xxxiv. p. 1. Nov. 1873.

then shines perpendicularly on the Moon's surface. Between the times of new and full Moon the boundary line of the illuminated portion (often called the terminator) has a rough jagged appear-

Fig. 34.

View of a portion of the Moon's Surface on the S.E. of Tycho. (*Nasmyth.*)

ance: this is caused by the Sun's light falling first on the summits of the peaks, the surrounding valleys and declivities being still in shade; thus a disconnected form is given to the whole edge, to which is due the jagged aspect above referred to.

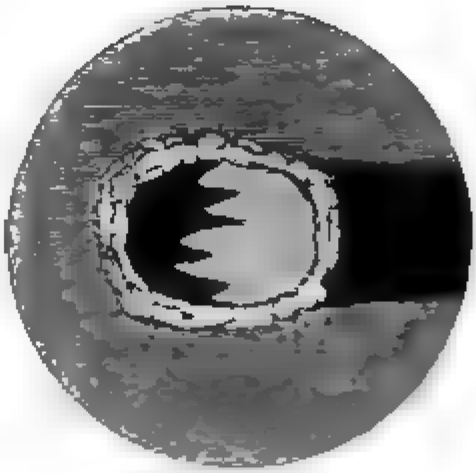
Most of the lunar mountains have received names, chiefly those of men eminent in science, both ancient and modern. Riccioli proposed this nomenclature as preferable to that of Hevelius, who adopted terrestrial geographical names. The Prussian astronomers Beer and Mädler, the selenographers to whom we owe so much of our knowledge of the Moon, measured the heights of 1095 lunar elevations, several of which exceed 20,000 feet.

Grey plains, or *seas*, analogous probably to our "steppes" and prairies, form another noticeable feature in the topography of the Moon. They were called seas from their supposed nature, but though the opinion is overthrown the appellation is retained, and specific names have been applied to several of them.

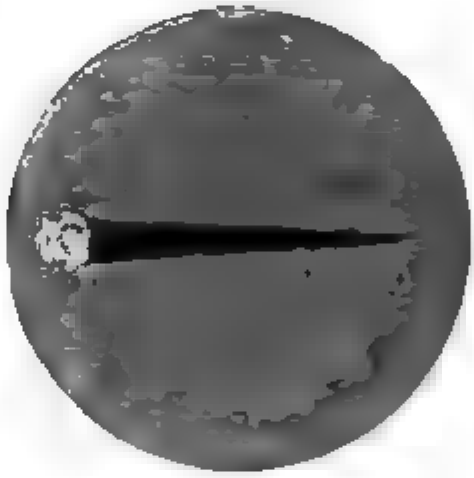
The *crater mountains* are by far the most curious objects shewn by the telescope. These are apparently of volcanic origin, and usually consist of a basin with a conical elevation rising from the centre. Their outline is generally circular or nearly so, but oblique view will often give those in the neighbourhood of the limb an apparently elliptical contour. Their immediate formation is probably due to the escape of gases from the interior of the Moon when that body was in a semi-fluid state, as it is conceived once to have been. The effect of the passage of air through a semi-fluid substance may be seen in the case of lime slaked by builders for fine plastering, when the air-bubbles, having forced their way upwards to the surface and burst, leave an aperture rising in a cone, forming a perfect imitation of many lunar craters. Several observers who have noticed a mountain named Aristarchus have fancied it to be a volcano in action. It is now generally understood that the faint illumination discerned on the summit is merely due to "Earth-shine;" but, in the words of Sir J. Herschel, "decisive marks of volcanic stratification, arising from successive deposits of ejected matter, and evident indications of lava currents streaming outwards in all directions, may be clearly traced with powerful telescopes. In Lord Rosse's magnificent reflector the flat bottom of the crater called Albategnius is seen to be strewed with blocks, not visible in inferior telescopes, while the exterior ridge of another (Aristillus) is all hatched over with deep gullies radiating towards its centre [e]."

[e] *Outlines of Ast.*, p. 283.

Figs. 35-37. *Plate* V.



ARCHIMEDES.



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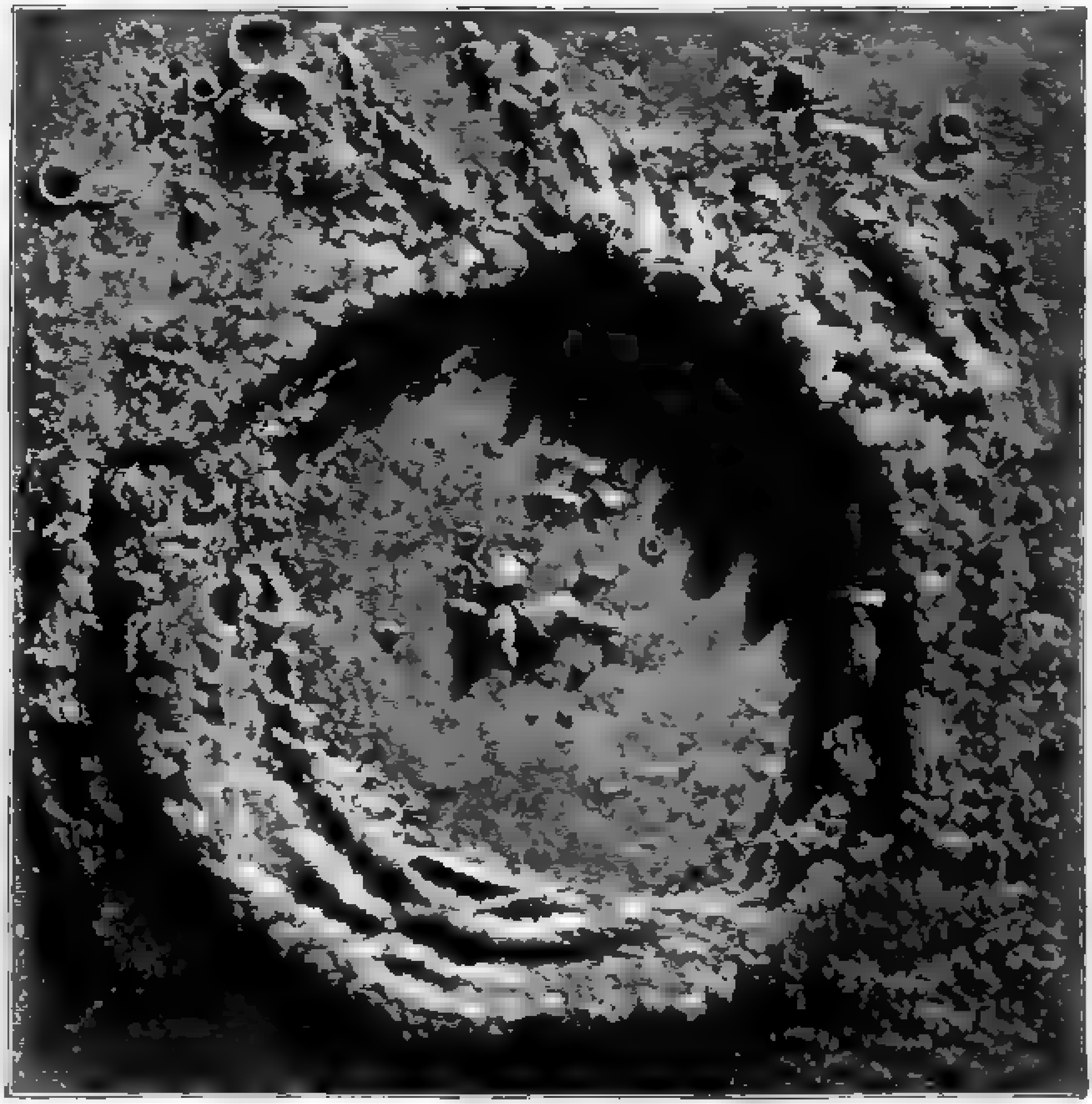


COPERNICUS. (*Nasmyth.*)

LUNAR MOUNTAINS.

A systematic topographical description of the Moon would be entirely beyond the compass of this work, and there is the less occasion for it as that by the Rev. T. W. Webb[f] is a very exhaustive one. The works of Hind[g] and Arago[h] also contain briefer accounts.

The question as to whether or not the Moon has an atmosphere[i] must be answered in the negative, though some affirmative testimony is forthcoming. Schröter considered that there was one, but he estimated the height at only 5376 feet, and Laplace thought it to be more attenuated than the best attainable vacuum of an air-pump. Schröter arrived at his conclusion by following up a remark of Auzout's[k], that if the Moon had an atmosphere the phenomenon of twilight would in consequence present itself. He was at length able, he thought, to determine that when the Moon exhibited a very slender crescent, a faint crepuscular light, extending from each of the cusps along the circumference of the unenlightened portion of the disc to a distance of 1′ 20″, could be perceived; its greatest breadth being 2″. He thence inferred the height of the atmosphere to be only 0·94″, corresponding to the 5376 feet given above[l]. The Moon would describe this arc in less than two seconds of time, and this circumstance was adduced by Schröter as an explanation of the difficulty attending its direct detection during eclipses and occultations. Sir J. Herschel considered that we are entitled to conclude the non-existence of any atmosphere at the Moon's surface dense enough to cause a refraction of 1″, *i. e.* having $\frac{1}{1980}$ the density of the Earth's atmosphere[m]. Both Beer and Mädler thought that the Moon has an atmosphere, but that it is of insignificant extent, owing to the smallness of our satellite's mass; and they also say, "It is possible that this weak envelope may sometimes, through local causes, dim or condense itself,"—an idea which, if proved, would help to clear up some of the conflicting details of occultation phenomena. The suddenness with which occultations of stars by the Moon take place is, however, commonly regarded as one of the best proofs that a lunar atmosphere

f *Celest. Objects*, pp. 59–129.
g *Sol. Syst.*, p. 48 *et seq.*
h *Pop. Ast.*, vol. ii. p. 258 *et seq.*, Eng. ed.
i See an important memoir by Bessel in *Ast. Nach.*, vol. xi. p. 411. July 16, 1834. And the reader will do well to consult a paper by Prof. Challis in *Month. Not.*, vol. xxiii. p. 231. June 1863.
k *Mém. Acad. des Sciences*, vol. vii. p. 106.
l *Phil. Trans.*, vol. lxxxii. p. 354. 1792.
m *Outlines of Ast.*, p. 284.

does *not* exist. And the spectroscope supplies negative evidence of like import.

"Professor Hansen has recently started a curious theory from which he concludes that the hemisphere of the Moon which is turned away from the Earth may possess an atmosphere. Having discovered certain irregularities in the Moon's motion, which he was unable to reconcile with theory, he was led to suspect that they might arise from the centre of gravity of the Moon not coinciding with her centre of figure. Pursuing this idea, he found upon actual investigation that the irregularities would be almost wholly accounted for by supposing the centre of gravity to be situated at a distance of 33½ miles[n] *beyond* the centre of figure. Assuming this hypothesis to be well founded, Professor Hansen remarks that the hemisphere of the Moon which is turned towards the Earth is in the condition of a high mountain, and that consequently we need not be surprised that [little or] no trace of an atmosphere exists; but that on the opposite hemisphere, the surface of which is situated *beneath* the mean level, we have no reason to suppose that there may not exist an atmosphere, and consequently both animal and vegetable life[o]." Professor Newcomb however has disputed these conclusions of Hansen.

For a few days, both before and after new Moon, an attentive observer may often detect the outline of the unilluminated portion without much difficulty. This lustre is the light reflected on the Moon by the Earth—"Earth-shine" in fact; the French call it *la lumière cendrée*, following the Latin *lumen incinerosum*, or the ashy light. In England it is popularly known as "the old Moon in the New Moon's arms." This light is stronger during the waning of the Moon than at any other time; as was noticed by Galileo, whose opinion was confirmed by Hevelius and other more modern astronomers. Hevelius remarked, moreover, that in the waning Moon the illumination is less intense than when the phases are increasing—a fact which would seem to indicate, as Arago has pointed out[p], that the Western part of the lunar disc is on the whole better adapted for reflecting the solar rays than the Eastern part; assuming this to be true, an obvious explanation is furnished

[n] "1740" in the English original, but erroneously so.

[o] Note by translator, Arago's *Pop. Ast.*, vol. ii. p. 276, Eng. ed.

[p] Arago, *Pop. Ast.*, vol. ii. p. 300, Eng. ed.

for the fact that the Earth-shine is more luminous before the New Moon than after it.

The *Harvest Moon* is the name given to that full Moon which falls nearest to the autumnal equinox; as our satellite then rises almost at the same time on several successive evenings, and at a point of the horizon almost precisely opposite to the Sun (so that the duration of its visibility is about the maximum possible), it is of much assistance to the farmer at that important period of the year. In the words of Ferguson, "The farmers gratefully ascribe the early rising of the full Moon at that time of the year to the goodness of God, not doubting that He had ordered it so on purpose to give them an immediate supply of moonlight after sunset, for their greater conveniency in reaping the fruits of the Earth[q]." Although this near coincidence in several successive risings of the Moon takes place in every lunation when our satellite is in the signs Pisces and Aries, yet the phenomenon is only prominently noticeable when it is full in these signs, which only occurs at or near the autumnal equinox, and when the Sun is in Virgo or Libra. The rationale of the harvest Moon is this:—Suppose the Moon to be full on the day of the autumnal equinox; the Sun is then entering Libra, and the Moon, Aries; the former setting exactly in the west, the latter rising exactly in the east: the southern half of the ecliptic is then entirely above the horizon, and the northern half entirely below, and the ecliptic itself makes the least possible angle with the horizon. The Moon in then advancing 13°, or one day's portion, in its orbit (which is but slightly inclined to the ecliptic) will become less depressed below the horizon, and will therefore have a less hour-angle to traverse by the diurnal motion after sunset in order that it may come into view the next night than at any other time[r]. That harvest Moon is (*astronomically*) most favourable which happens on Sept. 21, with the Moon in the ascending node of her orbit, which then coincides with the vernal equinox.

The Moon next after the Harvest Moon is (or used to be) called the *Hunter's Moon*.

The least possible variation between the times of two successive

[q] *Astronomy*, p. 136. Ed. of 1757.

[r] In Lockyer's *Elementary Lessons in Astronomy* (p. 172) there is a good diagram and description dealing with this matter.

risings is about 17^m, and the greatest possible about $1^h\ 16^m$, which takes place when the Moon is in Libra, and at the same time at or near its descending node.

As seen from the Sun, with the Earth in perihelion and the Moon in apogee, the Moon never departs more than $10'\ 42''$ from the Earth at its greatest elongation. Since the axis of the Moon is very nearly perpendicular to the plane of her orbit, our satellite has of course scarcely any change of seasons. At its equator the mean solar day has a constant length of $354^h\ 22^m$, or $14^d\ 18^h\ 22^m$ of our mean solar time; in other words, it is equal to half the period of the Moon's *synodical* revolution round the Earth. As is the case on the Earth, the length of the longest day on the one hand and of the shortest on the other increases and diminishes according as the assumed place of observation approaches the lunar poles: so that at the selenographic latitude of $45°$ these times become $14^d\ 21^h\ 19^m$ and $14^d\ 15^h\ 26^m$; and at the latitude of $88°$, $18^d\ 17^h\ 28^m$ and $10^d\ 19^h\ 16^m$ respectively.

By an observer placed on the Moon some astronomical phenomena would be witnessed under circumstances widely different from those under which we see them. The apparent diameter of the Earth would be about $2°$, and its apparent superficial extent 13 times greater than the apparent superficial extent of the Moon as seen from the Earth. More than this: the Earth is almost a fixed object in the lunar heavens, only altering its place by the amount of the libration, or traversing backwards and forwards a space having an extent of $15°\ 30'$ in longitude and $13°\ 18'$ in latitude. The Earth exhibits to the Moon exactly the same kind of phases which the latter does to us, but in *a reverse order*. For when the Moon is full, the Earth is invisible to the Moon; and when the Moon is new, the Earth is full to the Moon. These remarks apply only to those parts of the lunar surface which are turned towards our globe; for a spectator on the opposite side would never see the Earth at all, and spectators located on the apparent borders of the lunar disc would only now and then obtain a glimpse of it in their horizon, for which they would be indebted to the librations in longitude and latitude already noticed.

If the whole sky were covered with full Moons they would scarcely make daylight, for Bouger's experiments give the brilli-

ancy of the full Moon as only $\frac{1}{300000}$ that of the Sun. Wollaston's value is $\frac{1}{801072}$[s], Zöllner's $\frac{1}{618000}$, and G. P. Bond's $\frac{1}{470980}$[t].

The Moon's surface is supposed to be much heated, *possibly*, according to Sir J. Herschel, to a degree much exceeding that of boiling water[u], yet we are not in a general way conscious of there being any heat at all available for warming the Earth. This need not however excite surprise, for it is probably very small in amount, and what there is of it is doubtless quickly absorbed in the upper strata of our atmosphere. Melloni in 1846 thought that he detected a sensible elevation of temperature by concentrating the rays of the Moon in a lens 3 feet in diameter. C. P. Smyth in 1856 also thought that he obtained evidence on Teneriffe[x] of the Moon's rays possessing calorific power, but his instrumental means were not very perfect. Prof. Tyndall has stated that his experiments in 1861 seem to shew that the Moon imparts to us, or at least to the Professor's thermometric apparatus, "*rays of cold.*" More recently, however, the Earl of Rosse and M. Marié-Davy have conducted experiments which seem to give conclusively affirmative results, and on the whole the balance of evidence leans to this view of the question[y].

The first astronomer who paid much attention to the delineation of the Moon's surface was Hevelius, who in his well-known *Selenographia*, published in 1647, gave a detailed description of it, accompanied by one general and some 40 special charts; which, taking into consideration the inferior optical means at his disposal, were very creditable to the industry of the illustrious observer of Dantzig. Four years later Riccioli brought out a map of the Moon, having proper names assigned to many of the principal localities; and this nomenclature, improved and enlarged, is still in general use. J. D. Cassini and T. Mayer of Göttingen published charts in the years 1680 and 1749 respectively, the latter of which was the only one used by observers for many years subsequent to the opening of the present century. In 1791 Schröter published a

[s] *Phil. Trans.*, vol. cxix. p. 27. 1829.

[t] *Month. Not.*, vol. xxi. p. 200. May 1861.

[u] *Outlines of Ast.*, p. 285.

[x] *An Astronomer's Experiment, &c.*, p. 213.

[y] See a summary of all the experiments hitherto made given by Carpenter in *Pop. Sc. Rev.*, vol. ix. p. 1. January 1870. Lord Rosse's experiments will be found described in *Phil. Trans.*, vol. clxiii. p. 587. 1873. See also *Month. Not.*, vol. xxxiv. p. 197. Feb. 1874.

large work entitled *Selenotopographische Fragmente*, in which are given diagrams of many of the principal spots. Schröter was an industrious observer, but his descriptions are not always satisfactory.

In 1824, W. G. Lohrmann of Dresden published the first 4 of a series of 25 excellent lunar charts, but was prevented by failing sight from continuing the work. Beer and Mädler's elaborate *Mappa Selenographica* was published in 1837, and is undoubtedly the best of the kind yet published; but the most generally useful and also most generally accessible map for the class of readers whom I address is the Rev. T. W. Webb's, reduced from Beer and Mädler's. Undoubtedly, however, the most minutely accurate and elaborate lunar map yet made is the one of 7·67 feet in diameter, by Schmidt of Athens, but it is, unfortunately, not yet published. Maps by Russell and by Blunt are in circulation, but they are not of much value as regards details.

The British Association for the Advancement of Science, through a sub-committee, began in 1866 the preparation of an entirely new map of the Moon, but this has been now definitely abandoned by the Association, and is being very slowly carried on by Mr. W. R. Birt.

A wax model of the whole lunar surface was executed some years ago by a Hanoverian lady named Witte, and Nasmyth has modelled in plaster of Paris several single craters[1]. Photography, too, has been called in by De La Rue, Rutherford, and others, with good results.

In computing the places of the Moon the Tables of Burckhardt, published in 1812, were formerly used, but in 1862 the new and more perfect Tables of Hansen were introduced at the *Nautical Almanac* office; and these have entirely superseded Burckhardt's. Damoiseau, Plana, Carlini, Pontécoulant, Lubbock, and afterwards Delaunay, in addition to Hansen, did much to improve the theory of the Moon. Delaunay's labours earned for him a foremost place in the rank of geometrical astronomers. More recently still, Sir G. B. Airy has proposed to treat the lunar theory by a new method. He is still pursuing his investigations, and they will eventually

[1] Fig. 37 is from a photograph of one of these. But they are of little value, being very inexact.

be the foundation of Tables which will certainly supersede even Hansen's[a].

According to a recent determination by Stone the Moon's mass is $\frac{1}{81.36}$ that of the Earth.

To record a tithe of the influences ascribed to the Moon would be a herculean task, nevertheless (in addition to the tides) one deserves notice. Evening clouds at about the period of full Moon will frequently disperse as our satellite rises, and by the time it has reached the meridian a sky previously overcast will have become almost or quite clear. I first observed this in 1857, and *subsequently* found that Sir J. Herschel[b] had made the same remark. The idea has been disputed[c], but I am firmly convinced of its truth. Humboldt speaks of it as well known in South America, and Arago indirectly confirms the theory when he shews that more rain falls at about the time of new Moon (*cloudy period*) than at the time of full Moon (*cloudless period* according to the theory). According to Forster, Saturday new Moons result in 3 weeks of wet weather. He alleged that observations extending over 80 years shewed this coincidence[d].

[a] *Month. Not.*, vol. xxxiv. p. 89. Jan. 1874.

[b] *Outlines of Ast.*, p. 285.

[c] Ellis, *Phil. Mag.*, 4th ser., vol. xxxiv. p. 61. July 1867.

[d] *Month. Not.*, vol. ix. p. 37. Dec. 1848.

CHAPTER VIII.

THE ZODIACAL LIGHT.

General description of it.—When and where visible.—Sir J. Herschel's theory.—Historical notices.—Modern observations of it.

ASTRONOMICAL writers are not agreed as to the proper head under which to describe and discuss the Zodiacal Light. I prefer to deal with it here, because, whatever its origin, it is a matter of terrestrial cognizance, and therefore may, without any serious incongruity, be associated with the Earth.

The Zodiacal Light is a peculiar nebulous light of a conical or lenticular form[a], which may very frequently be noticed in the evening soon after sunset about February or March, and in the morning before sunrise about September. It extends upwards from the Western horizon in the spring and from the Eastern horizon in the autumn, and generally, though by no means always[b], its axis is nearly in a line with the ecliptic, or, more exactly, in the plane of the Sun's equator. The apparent angular distance of its vertex from the Sun's plane varies, according to circumstances, between 50° and 70°; sometimes it is more; the breadth of its base, at right angles to the major axis, varies between 8° and 30°. During its evening apparition it usually reaches to a point in the heavens situated not far from the Pleiades in Taurus. It is always so extremely ill-defined at the edges that great difficulty is experienced in satisfactorily determining its limits. In these northern latitudes the Zodiacal Light is generally, though not always, inferior in brilliancy to the Milky Way; but in the Tropics it is seen

[a] *Lens*, a lentil.
[b] *Month. Not.*, vol. xxx. p. 151. March 1870, *et infra*.

to far greater advantage. Humboldt says that it is almost constantly visible in those regions, and that he has himself seen it sufficiently luminous to cause a sensible glow on the opposite quarter of the heavens[c]. In the winter of 1842–43 it was remarkably well seen in this country, the apex of the cone attaining a length of no less than 105° from the Sun[d]. Mr. Lassell also mentions having seen the light very conspicuous at Malta in January 1850[e].

No satisfactory explanation has yet been given of this phenomenon; it is, however, very generally considered to be a kind of envelope surrounding the Sun, and extending perhaps nearly or quite as far as the Earth's orbit. Sir J. Herschel's opinion is, "that it may be conjectured to be no other than the denser parts of that medium which we have some reason to believe resists the motions of comets; loaded, perhaps, with the actual materials of the tails of millions of those bodies, of which they have been stripped in their successive perihelion passages [!!]. An *atmosphere* of the Sun, in any proper sense of the word, it cannot be; since the existence of a gaseous envelope propagating pressure from part to part—subject to mutual friction in its strata, and thereby rotating in the same, or nearly the same, time with the central body, and of such dimensions and ellipticity—is utterly incompatible with dynamical laws[f]." In connexion with this speculation it may be mentioned that during the visibility of the great comet of 1843 in March of that year, the Zodiacal Light was unusually brilliant; so much so, that by many persons it was mistaken for the comet.

The Zodiacal Light is of a reddish hue, especially at its base, where also it is most bright, and where it effaces small stars. Undulations and likewise a sort of flashing have been noticed in it.

It has been suggested that the Zodiacal Light is identical with what Pliny and Seneca call the "Trabes[g]," but more likely this was

[c] But on this point see Humboldt's later statement on p. 95, *post.*

[d] Detailed particulars will be found in the *Greenwich Observations*, 1842.

[e] For observations by E. J. Lowe, see *Month. Not.*, vol. x. p. 124, March 1850; vol. xi. p. 132, March 1851; and vol. xiv. p. 16, Nov. 1853. Observations by Burr and Webb will be found at pp. 45, 83, and 181 of the same volume; and see a paper by T. Heelis in *Mem. of the Lit. and Phil. Soc. of Manchester*, 3rd ser., vol. iii. p. 437.

[f] *Outlines of Ast.*, p. 658.

[g] *Hist. Nat.*, lib. ii. cap. 26.

the Aurora. Otherwise the historian Nicephoras must be regarded as the first to record the existence of this phenomenon. After describing the capture of Rome by Alaric in 410 A.D., he says:—"There then happened an eclipse of the Sun, during which the obscurity was so great that the stars appeared in broad daylight. .... There was seen at the same time in the sky, with the Sun eclipsed, and above him, a singular light, which in shape was like a cone, and which some ill-informed persons took to be a comet, but it had no star which could serve as a nucleus. It was rather a species of flame which subsisted by itself like a great lamp, whence there was diffused a light very different from that of the stars. . . . The position and movement of this object changed from time to time. It was at first placed in that part of the sky where the Sun rises at the vernal equinox; then it seemed to recline along that portion of the zodiac which answers to the last star in the Great Bear, always with its apex towards the west. After it had thus journeyed along the zodiac for more than 4 months it disappeared. Its summit became sometimes sharper, and gave it a form more oblong than that of a cone; after which it became shortened, and regained its former proportions. It had also other extraordinary forms, and resembled no known phenomenon. It commenced to shew itself in the middle of summer and lasted till the end of autumn[h]."

The Zodiacal Light was treated of by Kepler; afterwards by Descartes, about the year 1630; and then by Childrey, in 1659[i]; it was not, however, till J. D. Cassini, who saw it first on March 18, 1683, published some remarks on this phenomenon that much attention was paid to it[k].

In the year 1855, the Rev. G. Jones, Chaplain of the U. S. Steam-Frigate "Mississippi," published some remarks on this phenomenon[l], as brought under his notice during a cruise round the world in the 2 preceding years. He states: "I was also fortunate enough to be twice near the latitude of 23° 28′ north, when the

[h] Niceph., *Hist. Eccles.*, lib. xiii., quoted in Boillot's *Traité d'Astronomie*, p. 157.

[i] *Natural History of England*, 1659. *Brit. Bacon.*, p. 183. 1661.

[k] *Anc. Mém. de l'Acad. des Sciences*, vol. viii. p. 121.

[l] Gould's *Astronomical Journal*, No. 84, May 26, 1855. In the *Month. Not.*, vol. xvii. pp. 204-5, May 1857, are some distrustful remarks on this communication, to which the reader should refer, and at p. 47 is some account of J. F. J. Schmidt's work on the Zodiacal Light.

Sun was at the opposite solstice, in which position the observer has the ecliptic at midnight at right angles with his horizon, and bearing east and west. Whether this latter circumstance affected the result or not, I cannot say; but I there had the extraordinary spectacle of the Zodiacal Light simultaneously at both East and West horizons from 11 to 1 o'clock for several nights in succession."

Mr. Jones concludes his very interesting letter as follows:—"You will excuse my prolixity in stating these varieties of observations, for the conclusion from all the data in my possession is a startling one. It seems to me that those data can be explained only by the supposition of *a nebulous ring with the Earth for its centre, and lying within the orbit of the Moon* [m]."

On the publication of the foregoing, Humboldt transmitted to the Berlin Academy [n] some unpublished observations made by him at sea in March 1803, to the effect that on one or two occasions he also saw a 2nd light in the East contemporaneously with the principal beam in the West; he, however, *then* thought that the 2nd light was merely due to reflection. He concludes by saying that "the variations in the brightness of the phenomenon cannot, according to my experience, be accounted for solely by the constitution of our atmosphere. There remains much still to be observed relative to the subject."

Jones seems in one sense to have been anticipated in his "double end" view of the Zodiacal Light, as will appear from the following extract, which is here cited for a twofold purpose:—

"The two extremities of the Zodiacal Light may be seen on the same night about the time of the solstices, particularly the Winter solstice, when the ecliptic makes, night and morning, nearly equal angles with the horizon, and these are sufficiently great to allow a considerable portion of the points of the light to appear above the line of the twilight. It is thus that it was observed by Cassini on Dec. 4, 1687, at $6^h\ 30^m$ p.m. and $4^h\ 40^m$ a.m. the following morning [o]."

The most extensive recent observations on this subject which are

[m] See Jones's original memoir in vol. iii. of the 4to. ed. of the U.S. Exploring Expedition *Narrative*. (Washington 1856.)

[n] *Monatsbericht der kön. Preuss. Akademie der Wissenschaften*, July 1855. *Month. Not.*, vol. xvi. p. 16. Nov. 1855.

[o] J. R. Jackson, *What to Observe*, 2nd ed. p. 106.

of value are those made in the years 1869–71 by Captain Tupman in the Mediterranean. He confirms on many points previous observers, but contradicts them on one point very important. He asserts that the plane of the Light *does not pass through the Sun.* He also remarks having noticed great want of uniformity in the position of the axis of symmetry with respect to the ecliptic. In August and September the axis is frequently inclined as much as 20° to the ecliptic, whilst in the winter it is sensibly parallel to the ecliptic [p].

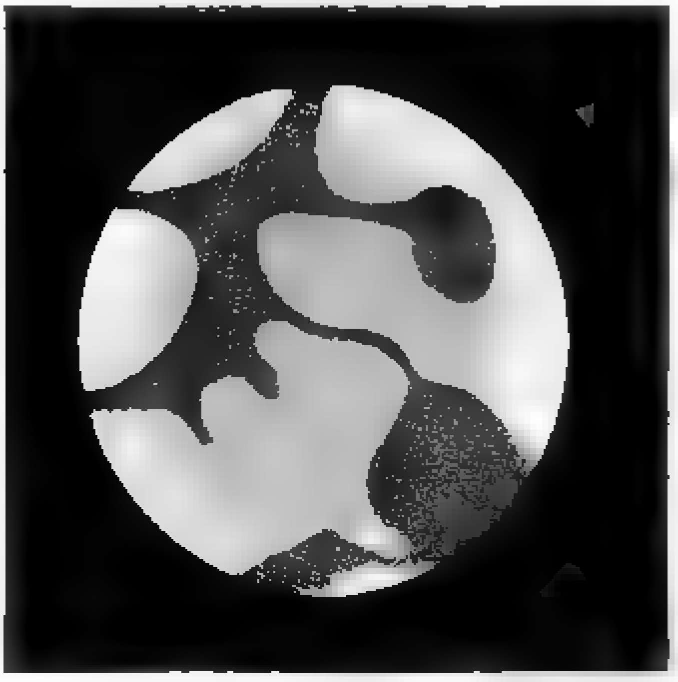
On December 19 and 20, 1870, when in Sicily, whither he had gone to observe the solar eclipse, Mr. A. C. Ranyard and some friends (Secchi amongst them) examined the Zodiacal Light through a Savart polariscope. His main conclusion is, that the Zodiacal Light consists of matter which reflects the Sun's light. He adds, that such matter either (1) exists in particles so small that their diameters are comparable with the wave lengths of light, or (2) is matter capable of giving specular reflection [q].

Some recently published observations by Birt are not unworthy of attention. They were made chiefly in 1850, though a few of his notes refer to April 1871. Birt draws attention to two special points:—(1) The fact that the greater portion of the Light always lies to the N. of the ecliptic; and (2) That comparing the shape of the cone of light month by month from February to April it becomes progressively more and more blunt, so much so "as to lead to the suspicion that we view the phenomenon differently as the Earth advances in her orbit from the point at which we beheld it in the winter months [r]."

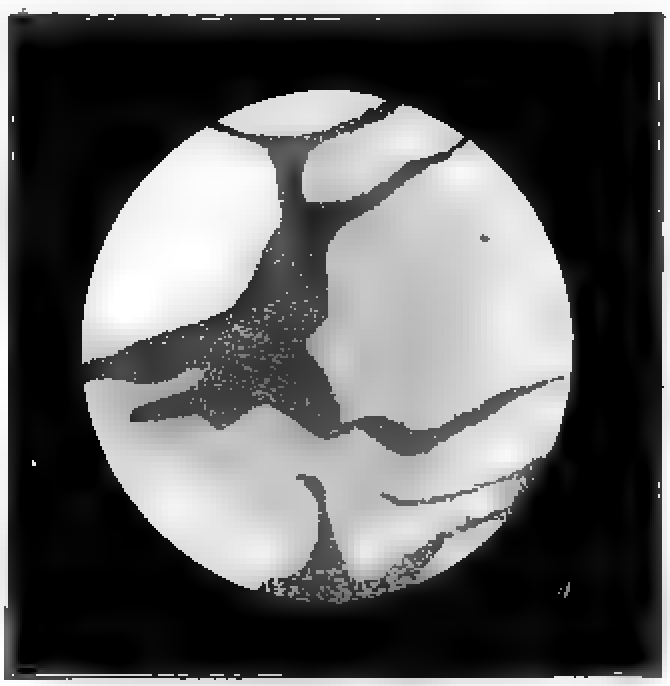
[p] *Month. Not.*, vol. xxxii. p. 74. Jan. 1872.

[q] *Month. Not.*, vol. xxxi. p. 171. March 1871.

[r] *Month. Not.*, vol. xxxi. pp. 177–82. April 1871.



1858: June 3.



1858: June 14.

MARS.

(*Drawn by Secchi.*)

CHAPTER IX.

MARS. ♂

Period, &c.—Phases.—Apparent motions.—Its brilliancy.—Telescopic appearance.—Its ruddy hue.—Polar snow.—Axial rotation.—The seasons of Mars.—Its atmosphere.—Has Mars a Satellite?—Ancient observation of Mars.—Tables of Mars.

MARS is the first planet exterior to the Earth in the order of distance from the Sun, and, as we shall presently see, bears a closer analogy to it than do any of the other planets.

Mars revolves round the Sun in $686^{d}\ 23^{h}\ 30^{m}\ 41^{s}$, at a mean distance of 139,312,000 miles, which an orbital eccentricity of 0·093 may augment to 152,284,000 miles, or diminish to 126,340,000 miles. The apparent diameter of Mars varies between 4·1″ in conjunction and 30·4″ in opposition; and owing to the great eccentricity of the orbit of Mars its apparent diameter as seen from the Earth will vary much at different oppositions. The diameter at mean distance of the planet from the Earth being 7·28″ (Le Verrier), the real diameter is about 4000 miles. Very varying results have been arrived at as to the compression of Mars. Sir W. Herschel gave it at $\frac{1}{16}$; Schröter contradicted this, and asserted that it must be less than $\frac{1}{80}$; Bessel merely decided that it was too small for measurement with his great heliometer at Königsberg[a]; Arago from Paris observations extending over 36 years (from 1811 to 1847) deduced $\frac{1}{30}$. Hind considers that $\frac{1}{51}$, and Main that $\frac{1}{39}$ is not very far from the truth. Kaiser's $\frac{1}{114}$ confirms Schröter.

Mars exhibits phases, but not to the same extent as the inferior planets. In opposition it is perfectly circular; between this and the quadratures it is gibbous; and at the minimum phase, which

[a] See his memoir in *Ast. Nach.*, vol. xxxv. p. 351. Dec. 17, 1852.

… at the quadratures, the planet resembles the Moon 3^{d} from the full. The character of these phases is a sufficient proof that Mars shines by the reflected light of the Sun. The phases of Mars were discovered by Galileo, who on Dec. 30, 1610 wrote to Castelli, "I dare not affirm that I can observe the phases of Mars; however, if I mistake not, I think I already perceive that he is not perfectly round."

After conjunction, when Mars first emerges from the Sun's rays, it rises some minutes before the Sun, and has a direct or Easterly motion; but since this motion is only half that of the Earth in the same direction, Mars appears to recede from the Sun in a *Westerly* direction, notwithstanding that its real motion among the stars is towards the East. This continues for nearly a year, and ceases when its angular distance from the Sun amounts to $\pm 137°$; then for a few days it appears stationary. After that, its motion becomes retrograde, or Westerly among the stars, and continues so until the planet is 180° distant from the Sun, or in opposition, and consequently on the meridian at midnight. At this period its retrograde motion is swiftest; it afterwards becomes slower, and ceases altogether when the planet is again at a distance of about 137° on the other side of the Sun. Its motion then again becomes direct, and continues so, till once more the planet is lost in the solar rays, when the phenomena are renewed, but with a considerable difference in the extent and duration of the movements. The retrogradation commences or finishes when the planet is at a distance from the Sun which varies from 128° 44′ to 146° 37′, the arc described being from 10° 6′ to 19° 35′; the duration of the retrograde motion in the former case is $60^{d}\ 18^{h}$, and in the latter $80^{d}\ 15^{h}$. The period in which all these changes take place, or the interval between one conjunction and one opposition, constitutes the synodical period, which amounts to 780^{d}. Mars and the Earth come *nearly* to the same relative position every 23^{y}; but several centuries elapse before precise coincidence occurs[b].

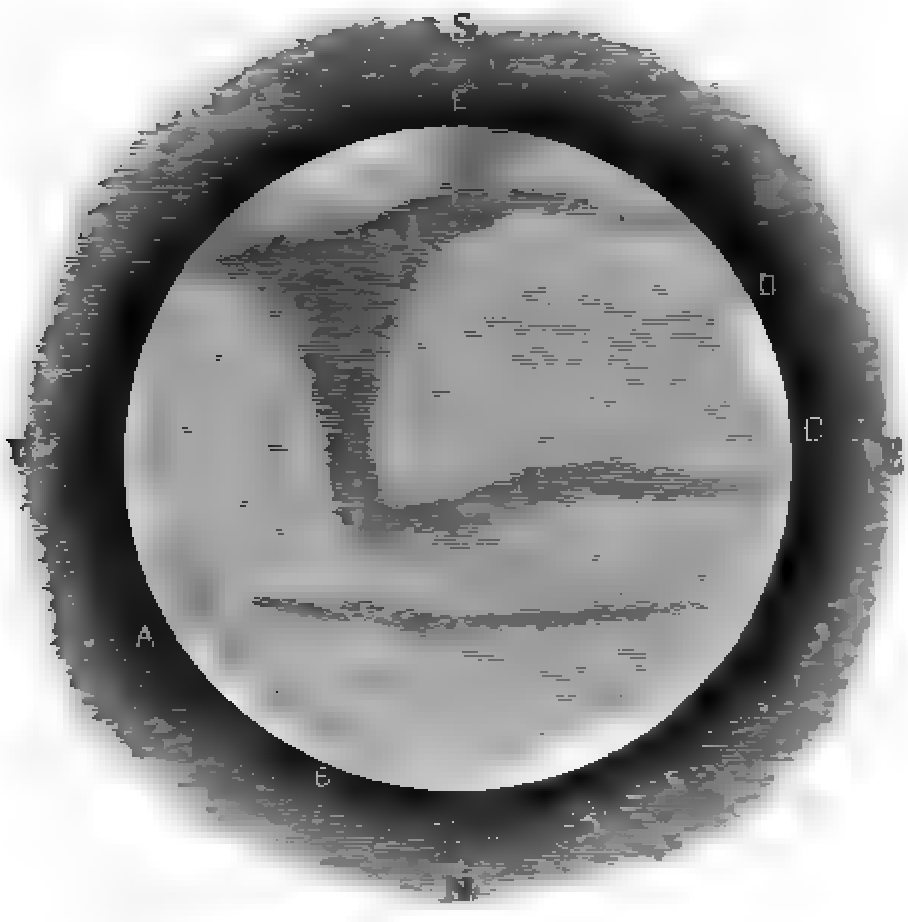
Mars when in opposition is a very conspicuous object in the heavens, shining with a fiery red light, which from its striking character has led to the planet being celebrated throughout the historic period. It received from the Jews on this account an

[b] Smyth, *Cycle of Celest. Objects*, vol. i. pp. 151–2,—abridged.

epithet equivalent to 'blazing,' and the Greek one (πυρόεις) bears much the same meaning. Its name or epithet in many other languages is substantially the same.

Its synodic period being 780 days, it comes to opposition, and therefore attains its (general) maximum brilliancy, once in rather more than 2^y. When in perihelion and in perigee at the same time, which occurs once in 4 synodical revolutions ($8^y\ 7^m$ about), Mars shines with a brilliancy rivalling that of Jupiter. In August

Fig. 40.



MARS, April 18, 1856. (*Brodie.*)[d]

1719, the planet being only 2½° from perihelion, its brightness was such as to cause a panic[c].

With suitable optical assistance, Mars is found to be covered with dusky patches, which have been supposed, and with good reason, to be continents analogous to those of our own globe: these are of a dull red hue; other portions, of a greenish hue, are believed to be tracts of water. The ruddy colour, which, over-

[c] De Zach, *Corr. Astronomique,* vol. ii. p. 293. March 1819.

[d] *Month. Not.,* vol. xvi. p. 205. June 1856.

powering the green, gives the tone to the whole of the planet, was believed by Sir J. Herschel to be due to "an ochrey tinge in the general soil, like what the red sandstone districts on the Earth may possibly offer to the inhabitants of Mars, only more decided [e]." In a telescope Mars appears less red than to the naked eye, and according to Arago [f] the higher the power the less the intensity of the colour. Webb writes:—"The disc when well seen is usually mapped out in a way which gives at once the impression of land and water: the bright part is orange,—according to Secchi, sometimes dotted with red, brown, and greenish points. Beer and Mädler think it much less red than to the naked eye; the darker spaces, which vary greatly in depth of tone, are of a dull grey-green (or, according to Secchi, bluish), possessing the aspect of a fluid absorbent of the solar rays. If so, the proportion of land to water on the Earth is reversed on Mars; on the Earth every continent is an island; on Mars all seas are lakes; so that the habitable area may possibly be much more alike than the diameter of the planets. From the different distribution of the water (if such it be) long narrow straits are more common than on the Earth. Dawes has observed a singular forked shading as if of 2 great contiguous estuaries [g]."

One point of contrast there is between Mars and the Earth. Whereas on the Earth the proportion of water to land is about 11 to 4, on Mars the proportions are probably about equal. It is to be noted also that the water on Mars is for the most part disposed in long narrow channels; of wide expanses of water, such as our Atlantic Ocean, there are few.

In the vicinity of the poles brilliant white spots may be noticed, which are now considered by astronomers to be masses of snow—an idea which is materially strengthened by the fact that they have been observed to diminish when brought under the Sun's influence at the commencement of the Martial summer, and to increase again on the approach of winter.

The observation of these white patches appears to date from the middle of the 17th century, for they seem to be noticed in a figure of the planet by Huyghens; Maraldi, in 1704, first gave specific

[e] *Outlines of Ast.*, p. 339.
[f] *Pop. Ast.*, vol. ii. p. 480. Eng. ed.
[g] *Celest. Objects*, p. 130.

representations of them. Sir W. Herschel[h], who discovered the circumstances attending their variation in size, found that they were not always precisely opposite, both being sometimes visible or invisible at the same time. Mädler noted the S. polar spot to undergo greater changes of magnitude than the Northern one, an observation harmonising with the fact that it experiences a greater variety of climate from the eccentricity of the planet's orbit. The same observer found (and herein he is confirmed by Secchi) the N. patch concentric with the planet's axis, but the S. one considerably eccentric, which agrees substantially with Sir W. Herschel's observation. It is not easy to understand why they are not exactly opposite; if both were equally removed, and in opposite directions, from the poles of rotation, it would occur, as with the Earth, that the poles of cold differed from those of rotation, but the subsisting facts are inexplicable.

Spots on the body of Mars led at an early period to attempts being made to ascertain the period of its axial rotation. J. D. Cassini, in 1666, found this to be effected in $24^h 40^m$; Hooke[i], working contemporaneously, was unable to decide between 12^h and 24^h. The most recent observations resting on a prolonged basis are those of Mädler[k], who fixed the time of revolution at $24^h 37^m 23^s$,—a result which singularly accords with Cassini's, and says much for the accuracy and skill of the astronomer of Bologna. Drawings by Hooke and by Huyghens more than 200 years old connected with modern observations led Kaiser to fix the period of Mars at $24^h 37^m 22{\cdot}62^s$, which Proctor corrects to $24^h 37^m 22{\cdot}71^s$. Sir W. Herschel's figures were $24^h 39^m 21{\cdot}67^s$; he stated, though on wholly insufficient data, that the obliquity of the ecliptic on Mars was 28° 42′—an angle so close to that which obtains for the Earth, as, if confirmed, to warrant us in asserting that the seasons of Mars are not materially different from our own.

The Martial year consists of 668 Martial days and 16 hours, the Martial day being longer than the terrestrial in the proportion of 100 to 97. Owing to the eccentricity of the planet's orbit, the summer half of the year in the Northern hemisphere consists of 372 days, the winter half being 296 days long. As a matter of course,

[h] *Phil. Trans.*, vol. lxxiv. p. 2 *et seq.* 1784.

[i] *Phil. Trans.*, No. 14.

[k] *Ast. Nach.*, vol. xv. No. 349. April 7, 1838.

the reverse state of things prevails in the Southern hemisphere; there the winter half-year consists of 372 days and the summer of 296 days. Nevertheless, although the extremes of temperature may, and probably do, differ widely in the two hemispheres, the mean temperatures of each may possibly differ but little. The duration of the seasons in Martial days in the Northern hemisphere is as follows:—Spring 191, summer 181, autumn 149, winter 147. For the Southern hemisphere we must reverse the seasons: this being done, it will appear that spring and summer taken together are 76 days longer in the Northern hemisphere than in the Southern.

The observations of Cassini led to the belief that Mars possessed a very extensive atmosphere: this has not been confirmed, and it is now only admitted that Mars has an atmosphere which is moderately dense. Sir J. South, who paid much attention to this subject, states that he has seen one star in contact with the planet and 2 occulted without change; thus overthrowing an opinion which resulted from an assertion of Cassini's that ψ Aquarii (a star of the 5th mag.) on one occasion, in Oct. 1672, disappeared in a 3-feet telescope when 6′ from the planet's limb.

As far as we know, Mars possesses no satellite, though analogy does not forbid, but rather, on the contrary, leads us to infer the existence of one; and its never having been seen, in this case at least, proves nothing. The 2nd satellite of Jupiter is only $\frac{1}{48}$ of the diameter of the primary, and a satellite $\frac{1}{48}$ of the diameter of Mars would be less than 100 miles in diameter, and therefore of a size barely within the reach of our largest telescopes, allowing nothing for its possibly close proximity to the planet. The fact that one of the satellites of Saturn was only discovered a few years ago renders the discovery of a satellite of Mars by no means so great an improbability as might be imagined.

The want of a satellite has prevented anything more than an approximation having been arrived at of the mass of Mars: Burckhardt made it $\frac{1}{2680337}$ of the Sun, Delambre $\frac{1}{2546320}$, Mädler $\frac{1}{2680800}$, and Le Verrier $\frac{1}{2994300}$. Airy has inferred from his researches on the solar theory that Delambre's estimate should be diminished in the ratio of 22 to 15. It is so far fortunate, Grant remarks, that the disturbing effects of this planet are so insignificant as to dispense with the necessity of extreme accuracy.

"The most ancient observation of Mars that has come to our

knowledge is one reported by Ptolemy in his *Almagest* (lib. x. cap. 9). It is dated in the 52nd year after the death of Alexander the Great, and 476th of Nabonassar's era, on the morning of the 21st of the month *Athir*, when the planet was above but very near the star β in Scorpio. The date answers to B.C. 272, Jan. 17, at 18h on the meridian of Alexandria. An occultation[1] of the planet Jupiter by Mars on Jan. 9, 1591, is recorded. Such a phenomenon would be extremely interesting if viewed with the powerful telescopes so common at the present day[m]."

In computing the places of Mars the tables of Baron De Lindenau, published in 1811, were generally used until recently, but they were superseded in 1861 by the more perfect tables of Le Verrier[n].

[1] Inasmuch as the apparent diameter of Mars is (except under rare circumstances) less than that of Jupiter, the more correct expression would probably be "a transit of Mars across Jupiter," &c.

[m] Hind, *Sol. Syst.*, p. 79.

[n] *Annales de l'Observatoire de Paris*, *Mém.* vol. vi. Paris 1861.

CHAPTER X.

THE MINOR PLANETS[a].

Sometimes called Ultra-Zodiacal Planets.—Summary of facts.—Notes on Ceres.—Pallas.—Juno.—Vesta.—Olbers's theory.—History of the search made for them.—Independent discoveries.—Progressive diminution in their size.

BETWEEN the orbits of Mars and Jupiter there is a wide interval, which, until the present century, was not known to be occupied by any planet. The researches of late years, as previously intimated in Chapter II., have led to the discovery of a numerous group of small bodies revolving round the Sun, which are known as the Minor Planets[b], and which have received names taken at the outset chiefly from the mythologies of ancient Greece and Rome, but in recent years from all sorts of sources, many names being most fantastic and ridiculous.

These planets differ in some respects from the other members of the system, especially in point of size, the largest being probably not more than, even if so much as, 200 miles or 300 miles in diameter. Their orbits are also, as a general rule, much more inclined to the ecliptic than the orbits of the major planets, whence they are sometimes termed the *Ultra-Zodiacal Planets*.

It is needless to give any detailed account of each, but a short summary may not be out of place.

[a] The use of symbols has been discontinued, except for the four early ones, as follows: Ceres ⚳, Pallas ⚴, Juno ⚵, Vesta ⚶; and even these are becoming obsolete.

[b] The old name of *asteroids*, proposed by Sir W. Herschel, has nearly fallen into disuse. Nothing could be more inappropriate than such a designation; *planetoids* would have been better. However, *minor planets* is preferable to either.

The nearest to the Sun is *Flora*, which revolves round that luminary in 1193^d, or $3\frac{1}{4}^y$, at a mean distance of 201,274,000 miles.

The most distant is *Freia*, whose period is 2299^d, or 6·3^y, and whose mean distance is 311,713,000 miles.

The least eccentric orbit is that of *Lomia*, in which ϵ amounts to only 0·023.

The most eccentric orbit is that of *Æthra*, in which ϵ amounts to 0·381.

The least inclined orbit is that of *Massilia*, in which ι amounts to 0° 41′.

The most inclined orbit is that of *Pallas*, in which ι amounts to 34° 42′.

The brightest and, presumeably, largest planet is *Vesta*. Lamont has assigned the place of honour to *Pallas* and given it a diameter of 670 miles, but this value is not to be relied on.

The faintest cannot be specified.

The more recently discovered planets are all so small that it is impossible to say which is the smallest.

It has been thought that many of the minor planets are variable in their light.

Several of the minor planets have been found only to be lost again, and their positions cannot now be determined. Included in this category are *Sylvia, Dike*, and *Camilla*. Others (*e.g. Lydia*) have been found again after being lost.

Under favourable circumstances *Ceres* has been seen with the naked eye, having then the brightness of a star of the 7th magnitude; more usually, however, it resembles an 8th magnitude star. The light is somewhat of a red tinge, and some observers have remarked a haziness surrounding the planet, which has been attributed to the density and extent of its atmosphere. Sir W. Herschel once fancied that he had detected 2 satellites accompanying *Ceres;* but its mass can scarcely be sufficient for it to retain satellites around it large enough to be visible to us. *Pallas*, when nearest the Earth in opposition, shines as a full 7th magnitude star, with a decided yellowish light. Traces of an atmosphere have also been observed. *Juno* usually shines as an 8th magnitude star, and is of a reddish hue. *Vesta* appears at times as bright as a 6th magnitude star, and may then constantly be seen without optical aid,

as was the case in the autumn of 1858. The light of *Vesta* is usually considered to be a pure white, but Hind considers it a pale yellow [c].

The orbits most nearly alike are those of *Fides* and *Maia*, and Lespiault has remarked that when at their least distance from each other these planets are separated by a space which only amounts to $\frac{1}{20}$ of the radius of the Earth's orbit, or about $4\frac{1}{2}$ millions of miles.

Sir J. Herschel remarks:—"A man placed on one of the minor planets, would spring with ease 60 feet, and sustain in his descent no greater shock than he does on the Earth from leaping a yard. On such planets giants might exist; and those enormous animals which, on Earth, require the buoyant powers of water to counteract their weight, might there be denizens of the land [d]." But to such speculations there is no end.

Respecting the past history, so to speak, of the minor planets, little can be said. Olbers, in calculating the elements of the orbit of *Pallas*, was forcibly struck with the close coincidence he found to exist between the mean distance of that planet and *Ceres*. He then suggested that they might be fragments of some large planet which had, by some catastrophe, been shivered to pieces. When this theory was started it appeared a not wholly improbable one, but the discoveries of late years have entirely exploded it [e]. Nevertheless, a very close connection does apparently exist between these minute bodies, and on this subject D'Arrest writes:—"One fact seems above all to confirm the idea of an intimate relation between all the minor planets; it is, that, if their orbits are figured under the form of material rings, these rings will be found so entangled, that it would be possible, by means of one among them taken at hazard, to lift up all the rest."

The circumstances which led originally to a search for planetary bodies in the space intervening betwen Mars and Jupiter, were these. In the year 1800, 6 astronomers, of whom Baron De Zach was one, assembled at Lilienthal, and there resolved to establish a

[c] *Sol. Syst.*, p. 85.

[d] *Outlines of Ast.*, p. 352.

[e] It may be shewn mathematically, that if the disruption of a large planet ever did occur, its fragments (no matter how diverse their subsequent paths might be) must, if continuing to revolve round the Sun, always pass through the point at which the explosion occurred, at one part of their orbits.

society of 24 practical observers, to examine all the telescopic stars in the zodiac, which was to be divided into 24 zones, each containing one hour of Right Ascension, for the express purpose of searching for undiscovered planets[f]. They elected Schröter their president, and the Baron was chosen their secretary. Such organisation was ere long rewarded by the discovery of 4 planets, but as no more seemed to be forthcoming, the search was relinquished in 1816.

It does not appear that any further labours in this field were prosecuted for some years, or till about the year 1830, when M. Hencke, an amateur of Driesen in Prussia, commenced to search for small planets, with the aid of the since celebrated Berlin Star Maps which contain all stars up to the 9^{th} or 10^{th} magnitudes lying within 15° of the equator. It is evident that a non-stellar body is much more likely to attract the notice of an observer possessing and using maps of this kind than of one not so provided, as a change of position virtually tells its own tale with *comparatively* little trouble to the astronomer. This series of maps, one for each hour of R. A., was only completed in 1859; therefore when Hencke commenced he had only a few at his command, and 15 years elapsed ere his zeal and perseverance produced any result: but when once one planet was found, the discovery of others quickly followed.

Several of these small planets were discovered independently by two or more observers, each without a knowledge of what the other had done. For example, *Irene* was found by Hind on May 19, 1851, and by De Gasparis on May 23; *Massilia* by De Gasparis on Sept. 19, 1852, and by Chacornac on Sept. 20; *Amphitrite* by Marth on March 1, 1854, by Pogson on March 2, and Chacornac on March 3 (3 separate discoveries); *Virginia* by Ferguson on Oct. 4, 1857, and by Luther on Oct. 19; *Eurynome* by Watson on Sept. 14, 1863, and by Tempel on Oct. 3; *Hecate* by Watson on July 11, 1868, and by Peters on July 14; *Cassandra* by Peters on July 23, 1871, and by Watson on August 6; &c.

Deducting duplicate discoveries, M. Peters carries off the palm for the largest number, for he has detected 22 minor planets. Then comes Luther with 21; Watson with 15; Goldschmidt with 13;

[f] See p. 46, *ante*.

Hind with 10; De Gasparis with 9; Pogson with 7; Chacornac and Borelly with 6; and so on[g].

The want of telescopes suitable and *available* for looking after minor planets tends now to hinder new discoveries. All the brighter planets have evidently been found; and, speaking generally, each new one is fainter than its predecessors, and consequently small telescopes are now incapable of doing the work. The following table will shew this better than any argument :—

			Mean Star Mag.
First Group:	Planets	1 to 10	8·5
Second „	„	11—20	9·6
Third „	„	21—30	10·4
Fourth „	„	31—40	11·0
Fifth „	„	41—50	10·9
Sixth „	„	51—60	11·2
Seventh „	„	61—70	11·3
Eighth „	„	71—80	11·6
Ninth „	„	81—90	11·6
Tenth „	„	91—100	11·4
Eleventh	„	101—110	11·5

The above numbers are not, it is true, in perfect sequence, and it is not possible to complete the Table at present, but my meaning will be sufficiently clear.

The figures in the column headed "Diameter" in the Table (see Appendix, *post*) are the results of calculations by Stone[h]. Photometric experiments made by Professor Stampfer of Vienna yielded somewhat similar results[i]. But both sets of figures are probably more relatively than absolutely accurate. Argelander published some suggestions for determining the brightness of these planets[k].

[g] Corrected to June, 1875.

[h] *Month. Not.*, vol. xxvii. p. 302. June 1867.

[i] See Bruhns's *De Planetis Minoribus*, Berlin 1856, for details. Some physical investigations by Newcomb into the orbits of certain of these planets will be found in *Mem. of the American Acad.*, vol. v. N.S. pp. 123–35: an abstract appears in *Month. Not.*, vol. xxi. pp. 55–7. Dec. 1860.

[k] *Month. Not.*, vol. xvi. p. 206. June 1856.

Flora, *Victoria*, *Melpomene*, and *Metis* are the only minor planets for the determination of whose places we as yet possess tables. It is not likely that this list will ever be much enlarged, for the increase of late years in the number of these planets has severely taxed the patience of astronomical computers.

CHAPTER XI.

JUPITER[a]. ♃

Period, &c.—Jupiter subject to a slight phase.—Its Belts.—Their physical nature.—First observed by Zucchi.—Dark Spots.—Luminous Spots.—Alleged Connection between Spots on Jupiter and Spots on the Sun.—Axial rotation of Jupiter.—Centrifugal force at its Equator.—Its Apparent Motions.—Astrological influences.—Attended by 4 Satellites.—Are they visible to the Naked Eye?—Table of them.—Eclipses of the Satellites.—Occultations.—Transits.—Peculiar aspects of the Satellites when in transit.—Singular circumstance connected with the interior ones.—Instances of all being invisible.—Variations in their brilliancy.—Observations of Eclipses for determining the longitude.—Practical difficulties.—Römer's discovery of the progressive transmission of light.—Mass of Jupiter.—Tables of Jupiter.

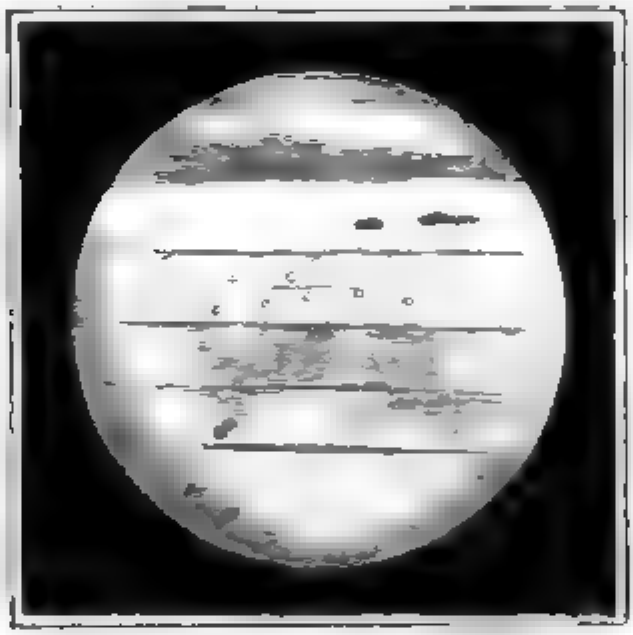
JUPITER, the largest planet of our system, revolves round the Sun in 4332·6[d] or 11·86[y], at a mean distance of 475,693,000 miles. The eccentricity of its orbit is 0·048, so the planet may recede from the Sun to 498,603,000 miles, or approach it to within 452,782,000 miles. The planet's apparent diameter varies between 50·7″ in opposition and 30·8″ in conjunction, being 37·91″ at its mean distance, according to very elaborate measurements by Main. The equatorial diameter is 88,400 miles or thereabouts. The compression is greater than that of any other planet, and amounts, according to the trustworthy observations of Main, to $\frac{1}{18.84}$. All the values of this quantity are closely of accord: *e. g.* Lassell gives $\frac{1}{17.88}$.

Jupiter is subject to a slight phase[b]: in quadratures it is gibbous: for reasons referred to when I was treating of Mars, the

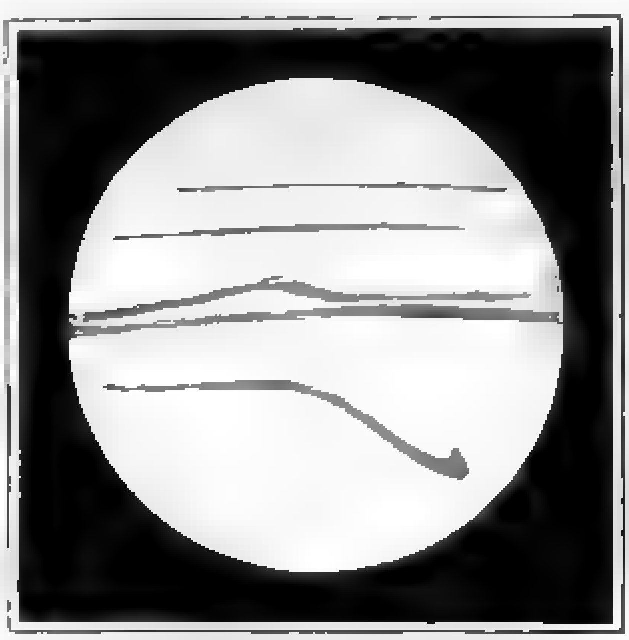
[a] Important modern delineations of Jupiter will be found as follows:—*Month. Not.*, vol. xxxi. p. 34. Dec. 1870 (Browning); vol. xxxiv. p. 235. March 1874 (the Earl of Rosse); vol. xxxiv. p. 403. June 1874 (Knobel).

[b] Sir J. Herschel says the contrary, but this is certainly an oversight.

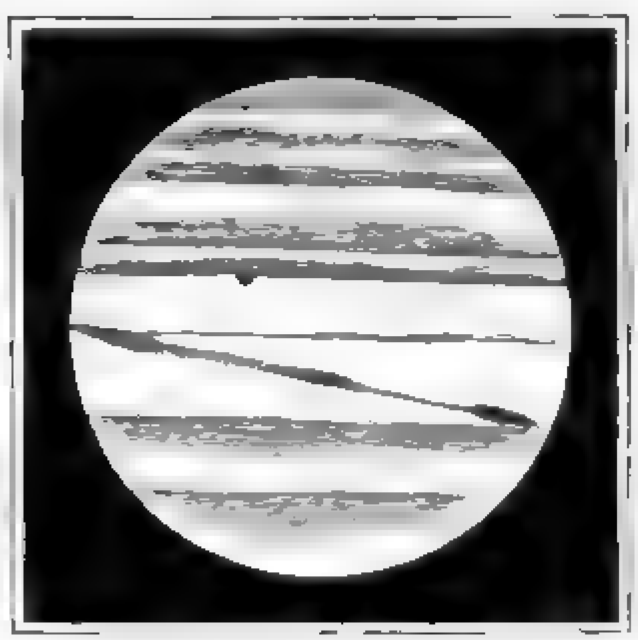
1857: November 27. (*Dawes.*)



1858: November 18. (*Lassel.*)



1860: March 12. (*Jacob.*)



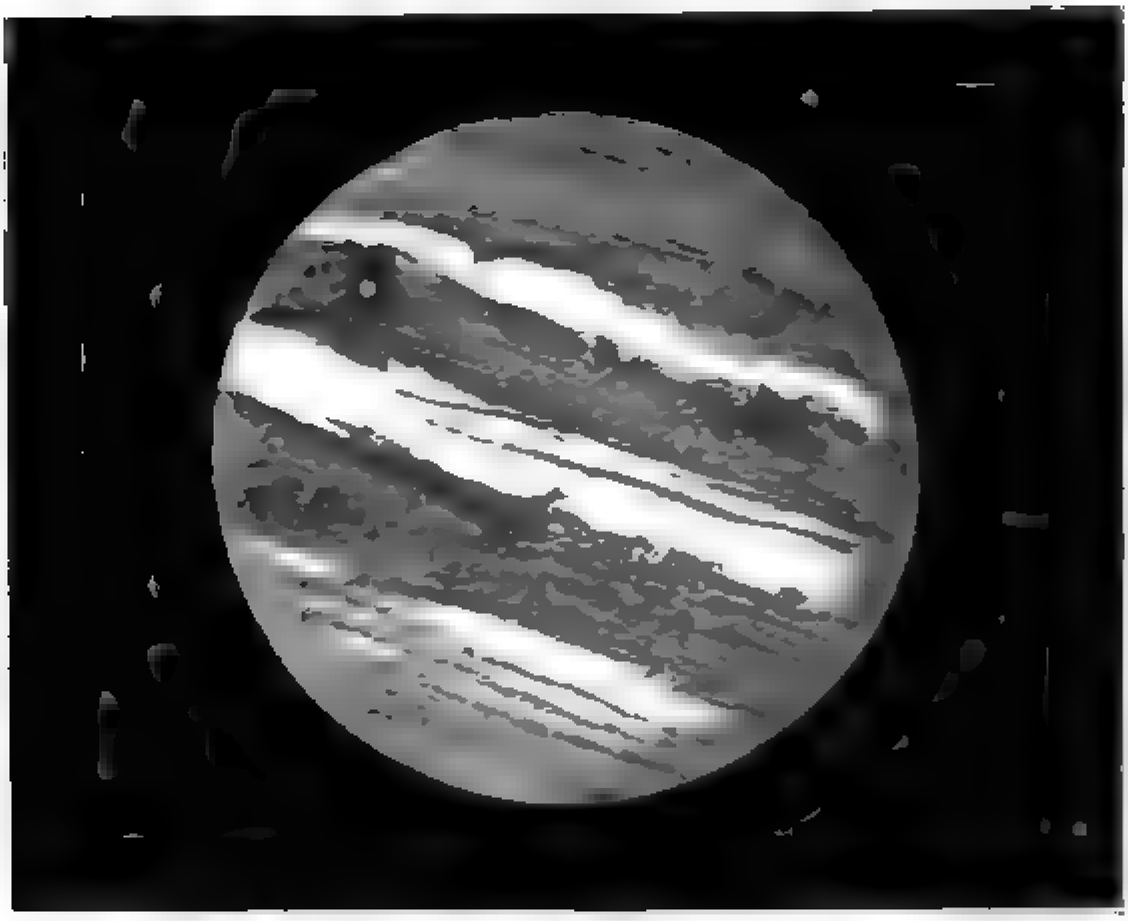
1860 April 9. (*Baxendell.*)

JUPITER.

illuminated portion always exceeds a semicircle, and in point of fact, owing to the greatly increased distance of Jupiter, the defalcation of light is very small, but perceptible nevertheless in the form of a slight shading off of the limb farthest from the Sun. Webb has noted that this is more easily seen in twilight than in full darkness.

The principal telescopic feature of Jupiter—its belts—are well

Fig. 45.



Jupiter, October 25, 1856. (*De La Rue.*)

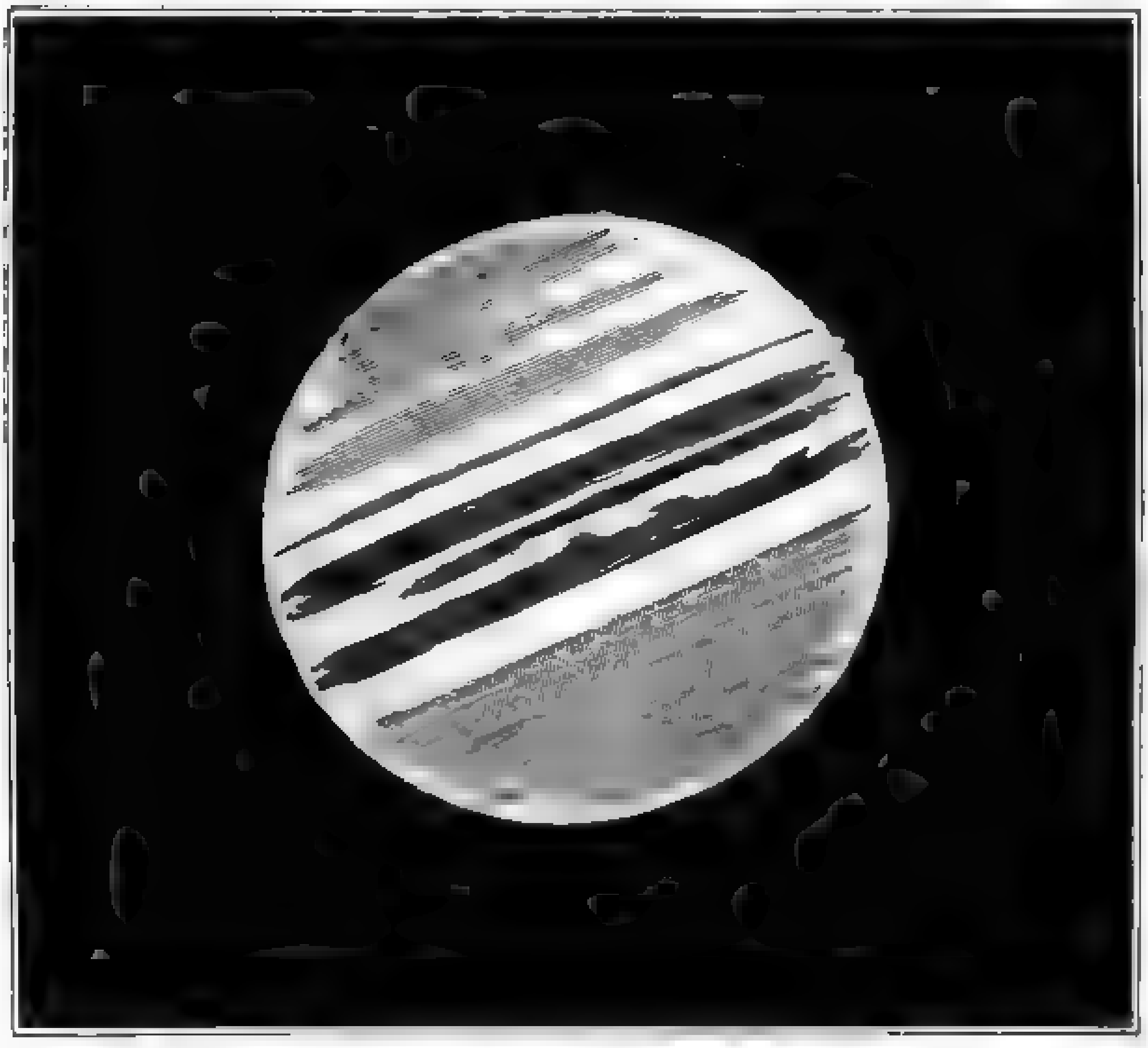
known, at least by name, to every one. These are dusky streaks of varying breadth and number, lying more or less parallel to the planet's equator[c]. It is supposed that the planet is enveloped in dense masses of cloud, and that the belts are merely longitudinal fissures in these clouds, laying bare the solid body beneath[d]. The belts, or, as we should with more propriety call them, the atmospheric fissures, are constantly changing their features: occasionally only 2 or 3 broad ones are seen; at other times

[c] A circumstance first remarked by Grimaldi in 1648.

[d] I have used the word "clouds" in the text, but their resemblance to the clouds of our own atmosphere must, for many reasons, be only remote.

as many as 8, 10, or even a dozen narrow ones appear. They are not permanent, but change from time to time, and occasionally with extreme rapidity; *e.g.* in the course of a few minutes; at other times the change they undergo is but gradual, and they retain nearly the same forms for several consecutive months. They are commonly absent immediately under the equator, but North

Fig. 46.



JUPITER, March 21, 1863. (*Gorton.*)

and South of this there is usually one wide streak and several narrower ones. At each pole the luminosity of the planet is feebler than elsewhere. The belts, distinguished from the general hue of the planet (often rose-coloured), are usually greyish; but superior power brings out traces of a brownish tinge, especially on the larger ones. Occasionally (as, for instance, during the years 1869–1872, according to numerous observers) the belts are characterised by much colour; "copper," "deep purple," "claret,"

"red," "orange," "Roman ochre," are some of the terms employed by Browning and others. A sketch by Lassell is annexed. He describes the colours recorded in the margin as "unmistakeable [e]." It is also to be remarked that they fade away towards the margin of the disc on either side—a circumstance which it may be presumed is connected with the fact that the portions of the planet's atmosphere near the limbs are necessarily viewed by us

Fig. 47.

Jupiter, Dec. 30, 1871. (*Lassell.*)

obliquely. Sometimes, but rarely, oblique belts may be seen [Figs. 43–4]; and with large telescopes sundry irregularities shew themselves, which in smaller instruments are merged in fewer and simpler outlines. The belts of Jupiter were first observed by Zucchi, at Rome, on May 17, 1630, according to Riccioli [f]; but a claim has been put in on behalf of Torricelli [g].

Spots are occasionally, but not very frequently, visible on Jupiter.

[e] *Month. Not.*, vol. xxxii p. 82. Jan. 1872.
[f] *Almag. Nov.*, vol. i. p. 486.
[g] Moll, *Jour. Royal Inst.*, vol. i. p. 494. May 1831.

Hooke makes the first record of one in May 1664[h]. He watched it in motion for about 2^h, and it seems to have been sheer idleness that led him to neglect observations of it for determining the planet's axial rotation—an honour reserved, as we shall presently see, for J. D. Cassini. Between Dec. 11, 1834 and March 19, 1835, a remarkable spot was observed at Cambridge by Airy: during a portion of this interval a second was seen. In 1843 a very large black spot was observed by Dawes, and in Nov. and Dec. 1858 two oblong dark spots were noted by Lassell as interesting objects[i]. *Luminous* spots closely resembling satellites *in transitu* were detected for the first time in 1849 by Dawes[k], and seen in the following year by Lassell[l]. In the autumn of 1857 Dawes again noticed some, and forwarded drawings of them to the Royal Astronomical Society, which will repay examination. On Oct. 25 he counted no fewer than 11, all clustered together in the Southern hemisphere[l]. In Nov. of the following year (1858) Lassell observed another cluster, in the Southern hemisphere, but nearer the equator than those seen by Dawes, and in a *bright* belt. It was much more difficult to catch these than the former ones. Luminous spots were observed also in 1858, 1859, and 1860 by Sir W. K. Murray[m], and in 1870 by various observers.

It is not known what is the physical nature of either the dark or the luminous spots, but recent observations by Mr. J. Brett indicate that the large white patches on the equatorial zone of Jupiter *cast shadows:* thus shewing that these patches project above the general surface visible to us. The appearances presented point to the conclusion that we do not see the actual body of the planet itself either in the dark belts or in the bright ones[n]. The usual form of both kinds of spots is more or less that of a circle.

It has been already pointed out in Chap. I. (*ante*) that some relationship has been thought to exist between Sun-spots as regards their period and the position of Jupiter in its orbit; but Ranyard extends this idea considerably. He points out an apparent identity in point of time between the prevalence of spots on the Sun and

[h] *Phil. Trans.*, No. 1.

[i] *Month. Not*, vol. xix. p. 52. Dec. 1858. One of them (in the drawing at least) is precisely like a garden slug!

[k] *Ibid.*, vol. x. p. 134. April 1850.

[l] *Ibid.*, vol. xviii. pp. 6 and 49. Nov. and Dec. 1857.

[m] *Month. Not.*, vol. xix. p. 51. Dec. 1858; *Ibid.*, vol. xx. p. 58. Dec. 1859; *Ibid*, vol. xx. p. 331. June 1860.

[n] *Month. Not.*, vol. xxxiv. p. 359. May 1874.

spots on Jupiter, and proceeds to infer that spots on Jupiter are indicative of disturbance on Jupiter, and that both classes of phenomena are dependent upon some extraneous cosmical change, and are in no sense related as cause and effect, the supposed cause being Jupiter's attraction, and the supposed effect an atmospheric tide on the Sun. The observations of Jupiter which are available for the confirmation of the truth of this theory are, previous to 1850, too few and too casual to be conclusive, but such as they are they have been tabulated by Ranyard, and unquestionably countenance his theory [o]. Browning suggests that evidence exists to shew that the red colour of Jupiter's belts is a periodical phenomenon coinciding with the epoch of Sun-spot maxima [p]. That in a general way the colour of Jupiter varies from time to time he is firmly convinced.

Cassini, by closely watching the spot which he first saw in July 1665, noticed movement, and regarded this as a proof of the planet's axial rotation, the period of which he found to be about $9^h\ 56^m$. The independent observations of Airy and Mädler in 1835 give $9^h\ 55^m\ 21{\cdot}3^s$ and $9^h\ 55^m\ 29{\cdot}9^s$, and afford another illustration of the care bestowed by Cassini on his astronomical researches. The later observations of Cassini, those of Sir W. Herschel, and those of Schröter indicate results not free from anomalies; Sir William's various determinations fluctuated to an extent of nearly 5^m, a discordance far beyond that which is assignable to errors of observation; and the unavoidable conclusion is that the spots employed by those 3 astronomers in their investigations were affected (as they themselves believed) by a proper motion of their own. Schmidt, a recent observer who has directed his attention to this matter, finds the period to be $9^h\ 55^m\ 28{\cdot}7^s$.

The axial rotation of Jupiter being so much quicker than that of the Earth, combined with its diameter being so much greater, results in the rotating velocity of a particle at its equator being greater than that of any other planet—466 miles per minute, against the Earth's 17 miles per minute. It will at once be perceived that the intensity of the centrifugal force must be very great, and the polar compression likewise. Hind calls attention to

[o] *Month. Not.*, vol. xxxi. p. 34. Dec. 1870; p. 201. May 1871; and p. 224. June 1871.

[p] *Month. Not.*, vol. xxxi. p. 75. Jan. 1871.

this rapid rotation as offering some compensation, by the heat which it must evolve, for the diminished power of the Sun's rays at the distance of Jupiter.

Under favourable circumstances Jupiter, like Mars, rivals Venus in brilliancy, and even casts a shadow. G. P. Bond found that for photographic purposes its surface reflects light better than that of the Moon in the ratio of 14 to 1[q]. Zöllner has calculated that Jupiter reflects 0·62 of the light it receives, the Moon reflecting but 0·17 of the incident light. Bond computed that Jupiter actually emits more light than it receives (!): but whether we accept this problematical result, or the more trustworthy one obtained by Zöllner, strong indications of inherent luminosity in Jupiter seem to exist; and this points to the conclusion that this planet is itself a miniature Sun. The heat derived from the Sun only would leave water on Jupiter's surface about 500° below freezing point, so that any *clouds* must arise from internal heat. Moreover, if we conceive the Earth and Jupiter to have been simultaneously created, Jupiter would retain its heat for ages after the Earth had cooled down.

Seen from the Earth the apparent motion of Jupiter is sometimes retrograde. The length of the arc of retrogradation varies from $9° 51'$ to $9° 59'$, and the time of its performance from $116^d\ 18^h$ to $122^d\ 12^h$. The retrograde motion begins or ends, as the case may be, when the planet is at a distance from the Sun which varies from $113° 35'$ to $116° 42'$[r].

In by-gone days Jupiter was not without its supposed astrological influences. It was supposed to be the cause of storms and tempests, and to have power over the prosperity of the vegetable kingdom. Pliny thought that lightning, amongst other things, owed its origin to Jupiter. An old MS. Almanac for 1386 states, that "Jubit es hote and moyste, and doos weel til al thynges, and noyes nothing."

Jupiter is attended by 4 satellites[s], all seen for the first time by

[q] *Month. Not.*, vol. xxi. p. 198. May 1861.

[r] It may here be noted that, as a general rule, the farther a superior planet is from the Sun, the less will be the extent of its arc of retrogression, but the greater will be the time occupied in describing it.

[s] Named by Simon Marius, a fraudulent claimant of their discovery, Io, Europa, Ganymede, Callisto. These names are not, and never have been in use, as it appears to have been thought that the admission of the nomenclature would savour of an admission of the claim.

Galileo, at Padua, on January 7, 1610[1], but not determined to be satellites till the following day. They shine with the brilliancy of stars of the 6th or 7th magnitude; but, owing to their proximity to their primary, are usually invisible to the naked eye, though several instances to the contrary are on record. Mr. C. Mason states that on April 15, 1863, finding Jupiter conveniently placed

Fig. 48.

Jupiter and its Satellites.

for the purpose, he determined to make a systematic attempt to solve the problem frequently declared to be an impossibility. After a steady gaze of 8^m or 10^m he was able to assure himself that in close proximity to Jupiter he could see a little star. Having resorted to various precautions to prevent self-deception he at length turned his refractor of 4¼ inches aperture on the planet

Fig. 49.

Jupiter seen with the Naked Eye, April 15, 1863. (*Mason.*)

and found in the position corresponding to that indicated by the naked eye (allowance being made for inversion) all the 4 satellites on the same side of the planet. He states that until referring to the *Nautical Almanac* a few minutes before using the telescope he had no idea as to their configuration, and is the more convinced

[1] *Siderius Nuncius; Opere di Galileo*, vol. ii. p. 15 *et seq.* Ed. Padua, 1744.

that with the naked eye he really did see the 4 as *one*[u]. It is quite certain that satellites II and III were seen on Jan. 15, 1860, by some officers of H. M. S. "*Ajax*," in Kingston Harbour, Dublin[x]. Mr. Levander and others at Devizes asserted that on April 21, 1859, they saw 2 of these bodies. In 1852 an American missionary of the name of Stoddard, at Oroomiah in Persia, repeatedly saw two

Fig. 50.

JUPITER SEEN WITH A TELESCOPE, April 15, 1863. (*Mason.*)

satellites in the twilight, so long as Jupiter itself was devoid of an overpowering glare. Wrangel, the celebrated Russian traveller, states that when in Siberia he once met a hunter who said, pointing to Jupiter, "I have just seen that large star swallow a small one, and vomit it shortly afterwards." The Russian remarks that the sportsman here referred to an immersion and subsequent emersion of the III^rd^ satellite, on which Arago, who makes the citation, says, "It is well known that the acuteness of sight of those natives and of the Tartars has become proverbial." Other similar observations, including one by himself, are given by Webb[y], so that we may now regard the question of possibility as decided in the affirmative.

The satellites of Jupiter are capable of being seen with so little optical assistance that it is worth while to enter at some length into a consideration of them.

They are distinguished by ordinal numbers proceeding outwards. Thus the "I^st^" satellite is the one nearest to the primary; the "IV^th^" the one most distant therefrom. To determine which is which, the diagrams given in the *Nautical Almanac* will usually be necessary, but the III^rd^, as the largest and brightest, will generally

[u] *Month. Not.*, vol. xxiii. p. 215. May 1863.
[x] *Month. Not.*, vol. xx. p. 212 March 1860.
[y] *Celest. Objects*, p. 144.

THE SATELLITES OF JUPITER.

	Discoverer.	Mean Distance.		Sidereal Period.		Mean Apparent Diam.	Diam.	Diameter seen from ♃'s Equator.	Apparent Diam. of ♃, seen from Satellite.	Max. Elong. ♃ in ☍	Mass ♃ = 1 (Laplace).	Density.		Appar. Star Mag.
		Radii of ♃	Miles.									⊕ = 1.	Water = 1.	
				d. h. m.	d.	"	Miles.	′ ″	° ′	′ ″				
1. Io	Galileo,	6·05	267,300	1 18 28	1·77	1·02	2350	38 11	19 49	2 15	0·000017	0·20	1·12	7
2. Europa ..	Padua,	9·62	425,100	3 13 14	3·55	0·91	2090	17 35	12 25	3 35	0·000023	0·38	2·14	7
3. Ganymede	Jan. 7,	15·35	678,300	7 3 43	7·15	1·49	3430	18 0	7 47	5 46	0·000088	0·33	1·87	6
4. Callisto .	1610.	26·99	1,192,800	16 16 32	16·69	1·27	2920	8 46	4 25	9 45	0·000043	0·26	1·47	7

The duration of an eclipse of the Ist is 2ʰ 20ᵐ
" " IInd 2 56
" " IIIrd 3 43
" " IVth 4 56

—(*Nautical Almanac*, 1835.)

The Eccentricity of the orbits of I and II is = 0: of III and IV is "small and variable."
The Inclination of the orbit of IV is slowly increasing.

be identified with least difficulty. In small telescopes it is scarcely possible to say that there is anything to distinguish the satellites from stars, beyond a noticeably greater steadiness of light; increased power will reveal discs, but a very considerable augmentation is requisite for detecting physical peculiarities. "The discovery of 4 bodies revolving round a primary, exhibited a beautiful illustration of the Moon's revolution round the Earth, and furnished a most favourable argument in favour of the Copernican theory[a]. The announcement of this fact pointed out also the long vista of similar discoveries which have continued from time to time down to the present day to enrich the solar system, and to shed a lustre on the science of astronomy."

The eclipses, occultations, and transits of the Jovian satellites offer an endless series of interesting, and indeed useful, phenomena. The **I**st, **II**nd, and **III**rd satellites, in consequence of the smallness of the inclinations of their orbits, undergo once in every revolution an eclipse in the shadow cast by the planet into space. The **IV**th, however, frequently escapes this ordeal, in consequence of the plane of its orbit being somewhat more inclined than is the case with the others, and its distance from the primary being so considerable.

When the satellites enter the shadow the *immersion* is said to take place; when they come out of it, the *emersion*—terms which explain themselves. Closely associated with the eclipses are the occultations—a word employed to express the concealment of the satellites by the direct interposition of the planet itself, independently of the shadow. When the planet has passed its conjunction with the Sun, the shadow is projected on the Western side, and at this time both the immersions and emersions of the **III**rd and **IV**th satellites may be observed, but not always those of the **II**nd; and only the emersions of the **I**st, in consequence of its proximity to the planet causing it (after first undergoing an occultation) to enter the shadow behind the planet. When Jupiter is near its opposition to the Sun, the immersions and emersions take place very close to the planet's limbs. As the planet again approaches conjunction the shadow is projected on the Eastern side, giving

[a] The argument, however, failed to command the acceptance of divers Popes and Romish ecclesiastics, who assailed Galileo's views respecting these satellites with great bitterness for a long series of years.

rise to phenomena partly complementary to those set forth above. In other words, whilst the immersions and emersions of III and IV are always visible, and those of II frequently visible, the immersions only of I can be perceived because it emerges behind Jupiter; when this one does reappear it is on emersion *from an occultation*.

The occultations "generally require much more powerful instruments for their satisfactory observation than the eclipses. With a telescope of adequate power we may trace the gradual disappearance of the satellite from the first contact with the limb of the planet to its final obscuration behind the disc; and, as viewed with such an instrument, these phenomena are highly interesting. The occultations of the IVth satellite are usually visible throughout, *i. e.* from disappearance to reappearance; those of the IIIrd also are frequently observable. But it happens much more rarely that the complete phenomenon can be observed in regard to the IInd satellite, while the immersion and emersion of the Ist can only be visible a day or two before or after the opposition of Jupiter, as at all other times either the immersion or emersion must happen while the satellite is obscured in the planet's shadow. Thus it most usually occurs that from conjunction to opposition the *reappearances* only of the Ist and IInd satellite can be observed, and the *disappearances* only from opposition to conjunction[a]."

Far more interesting are the transits of the satellites and their shadows across the planet—phenomena which, it is easy to understand, are of frequent occurrence when the satellites are in those parts of their respective orbits which lie nearest to the Earth. The satellites appear on the disc of their primary as round luminous spots preceded or followed by their shadows, which shew themselves as round black or blackish[b] spots. The shadow precedes the satellite when Jupiter is passing from conjunction to opposition, but follows it when the primary is between opposition and conjunction. When actually in conjunction the shadow is in a right line with the satellite, and the two may be superposed.

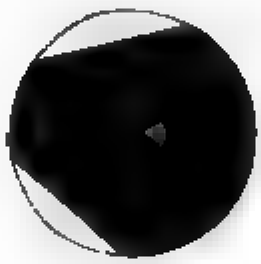
Some peculiarities in the appearance of the satellites during

[a] Hind, *Sol. Syst.*, p. 100.

[b] *Blackish*, because the visible margin is not that of the true shadow, but of a penumbra which surrounds the shadow, though it is rare for this penumbra to be observable as an actual ring surrounding the shadow (see an instance recorded by T. H. Buffham in *Ast. Reg.*, vol. viii. p. 37. Feb. 1870).

transit are too well attested to be passed over. **III** in particular is nearly always seen almost or quite as dark as its shadow, but on rare occasions appears dusky and shaded. **IV** has recently been often so seen[c], but, according to Dawes, **II** has never had the slightest shading on its disc within his knowledge, and **I** only a grey tinge, inferior by many shades to that usually possessed by **III**. Contrast has evidently a good deal to do with the bringing out of these shadings, but the circumstances attending the recorded variations in this intensity are less intelligible. J. D. Cassini, Maraldi, Pound[d], Messier[e], Schröter, and Sir W. Herschel are amongst the earlier observers of these peculiarities, and W. C. Bond, Lassell, and Dawes amongst the more recent ones. Bond saw **III** as a well-defined black spot on Jan. 28, 1848, and again on March 11. On March 18 he states that it entered upon the disc as a very bright spot, more brilliant than the surrounding

Fig. 51.

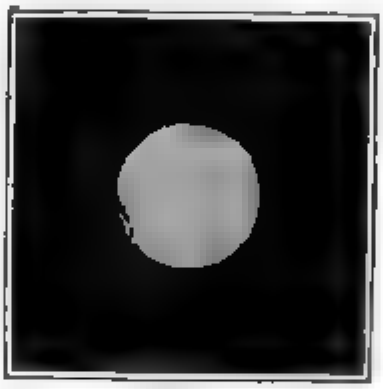


THE IVth SATELLITE OF JUPITER, March 26, 1873. (*G. W. Roberts.*)

Fig. 52.

THE IIIrd SATELLITE OF JUPITER, Jan. 31, 1860. (*Dawes*)

Fig. 53.



THE IVth SATELLITE OF JUPITER, Feb. 12, 1849. (*Dawes.*)

surface; that 20^m later it had so decreased in brightness as to be hardly perceptible, and that in another few minutes a dark spot suddenly appeared in its place, which was seen for $2\frac{1}{4}^h$. This spot was sufficiently conspicuous to be measured with a micrometer, was perfectly black, nearly round, and *on* the satellite. The converse

[c] Roberts (*Month. Not.*, vol. xxxiii. p. 412. April 1873); Firmstone (*Ibid.*, p. 460. May 1873); Burton (*Ibid.*, p. 472. June 1873), &c. On Aug. 21, 1867, Prince saw IV as a "round black spot," its colour being as nearly as possible that of its own shadow" (*Month. Not.*, vol. xxvii. p. 318).

[d] *Phil. Trans.*, vol. xxx.

[e] *Phil. Trans.*, vol. lix. p. 459. 1769.

of this—the satellite dark first and bright afterwards—was witnessed by Prince and Brodie on Jan. 31, 1860 [f].

On June 26, 1828, **II**, having entered on the disc of Jupiter, was seen 12^m or 13^m afterwards *outside* the limb, where it remained visible for at least 4^m and then suddenly vanished. Three observers of eminence (Sir T. Maclear, Adm. Smyth, and Dr. Pearson) record this, so there can scarcely have been any individual optical illusion, much less deception. It has been suggested that an eclipse of the satellite by another satellite would meet the facts of the case, provided we could establish a doubt as to whether these observers for a certainty saw the satellite previously *on* the disc of the planet.

Lassell has found the shadow of **IV** very much larger than the satellite itself, even to the amount of double the diameter, and the same shadow larger than that of **III**, though the satellite itself is smaller than **III**. The shadow of **II** has been seen, it is said, to possess an irregular outline, but the observation is not well attested.

On April 5, 1861, Mr. T. Barneby saw the shadow of **III** first in the shape of a broad dark streak such as the cone of the shadow would represent in a slanting direction, "but it shortly afterwards appeared as a circular spot perfectly dark and much *larger* than the shadow (which was visible at the same time) of the third satellite" (*sic*). There is some mistake in this latter clause (the shadow of **I** is probably referred to), but I cite the passage because of the information about the form of the projection of the shadow, which though very reasonable and obvious is noticeable as the only instance I have met with.

On April 17, 1861, the Rev. R. Main saw satellite **II** occulted by **I**, and the two appeared as one for some 7^m or 8^m.

On Jan. 14, 1872, Mr. F. M. Newton saw the I[st] satellite superposed on its shadow, so that the satellite appeared to be surrounded by a dark ring. This observation appears to be unique [g].

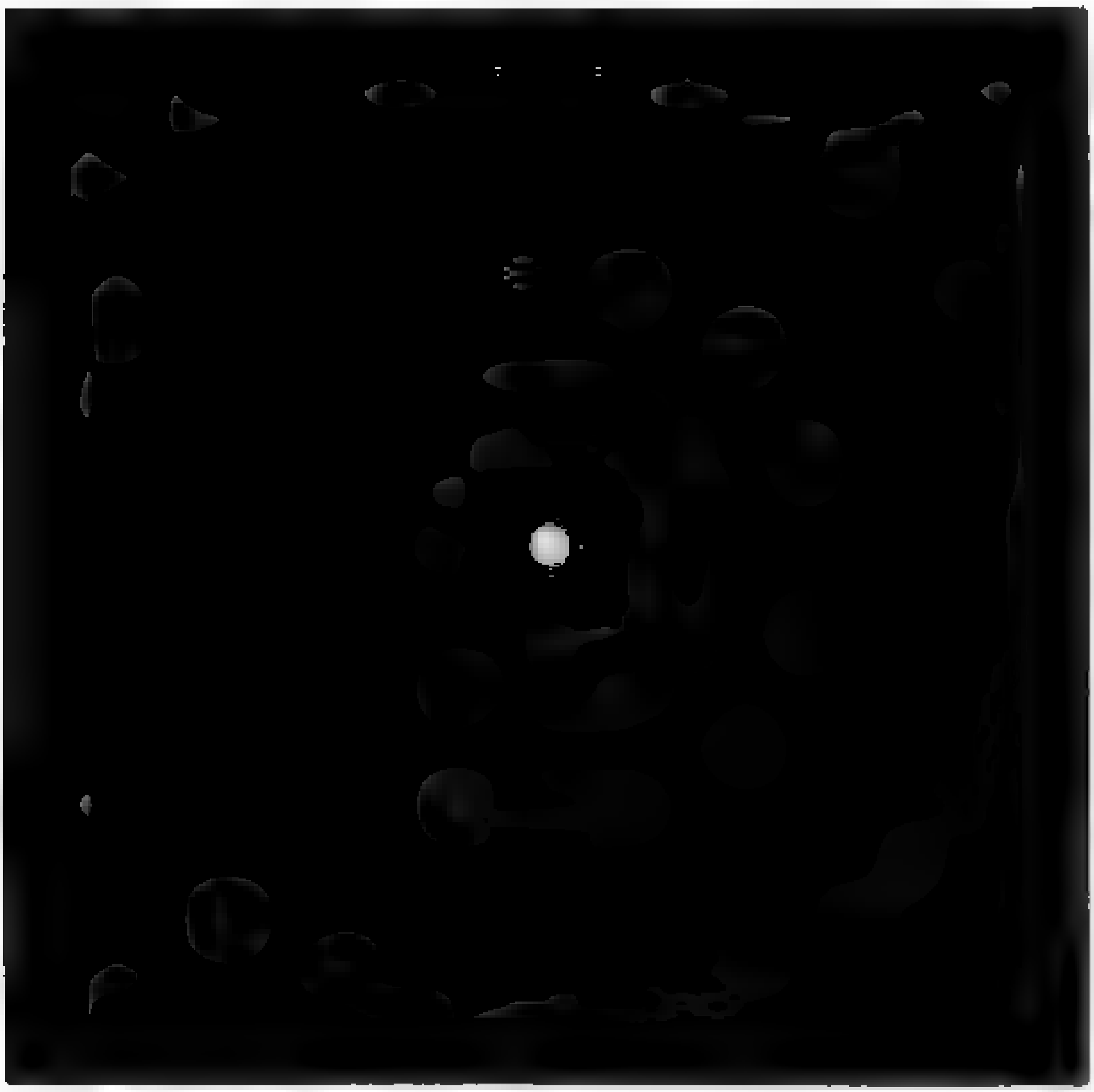
As to certain irregularities of figures presented by satellite **IV** when seen as a dark spot on the disc of Jupiter, reference may be made to a paper by Burton [h].

Jupiter's satellites move in orbits nearly circular, and between the motions of the first three a singular relation exists:—*The mean*

[f] *Month. Not.*, vol. xx. p. 212. March 1860.
[g] Letter in *Engl. Mech.* vol. xiv. p. 5:5. Feb. 9, 1872.
[h] *Month. Not.*, vol. xxxiii. p. 472. June 1873.

sidereal motion of the I^st added to twice that of the III^rd, is constantly equal to three times that of the II^nd; so that the sidereal longitude of the I^st, plus twice that of the III^rd, minus three times

Fig. 54



PLAN OF THE JOVIAN SYSTEM[1].

that of the II^nd, yields a remainder always constant, and in fact equal to 180°. This relation will be better understood by an inspection of the following table:—

	Sidereal motion per second of time.				
Satellite I.	8·478706	× 1	= 8·478706.		(*a*)
„ II.	4.223947	× 3	= 12 671841.		(*b*)
„ III.	2·096567	× 2	= 4·193134.		(*c*)
„ IV.	0·898795.				

[1] The satellite orbits in this and the following chapters are all drawn to the same scale.

Adding together a and c, we get 12·671840, which quantity is to 5 places of decimals the same as b. From this it follows that for an enormous period of time the 3 interior satellites cannot all be eclipsed at the same time; for in the simultaneous eclipses of the II^nd and III^rd the I^st will always be in conjunction with Jupiter, and so on [j]. Making use of his own tables, Wargentin has calculated that simultaneous eclipses of the 3 satellites cannot take place before the lapse of 1,317,900 years[k], and an alteration of only 0·33″ in the annual motion of the II^nd satellite would suffice to render the phenomenon for ever impossible.

D'Arrest has pointed out the commensurability, within a few hours, of 5187 revolutions of the I^st satellite, 2583 of the II^nd, 1281 of the III^rd, and 548 of the IV^th, in 25^y 55^d, when the same geocentric configuration will recur.

The exact figures are given by him[l] as follows :—

	Days.				Days.
Satellite I.	1·77	×	5187	=	9180·27.
„ II.	3·55	×	2583	=	9180·23.
„ III.	7·15	×	1281	=	9180·14.
„ IV.	16·69	×	548	=	9180·95.

Between the III^rd and the IV^th satellites the following comparatively coarse approximation subsists. *Seven* times the period of the former (50^d 1^h 57^m $53^s.520$) exceeds by only 21^m $19^s.7$ *three* times the period of the latter (50^d 1^h 36^m $33^s.813$).

The following special elements are given by Hind[m]. "The line of apsides of the III^rd satellite revolves in about 137^y, and that of the IV^th in about 516^y. The lines of nodes of the 3 exterior satellites revolve in a *retrograde* direction, as is the case with the nodes of the lunar orbit; the period for the II^nd is 30^y, for the III^rd 140^y, and for the IV^th 520^y."

It occasionally, but very rarely, happens that all 4 satellites are for a short time invisible, being either directly in front of, or behind, the planet. Such was the case, according to Molyneux[n], on Nov. 2, 1681 (O. S.) The same thing was noticed by Sir W. Herschel on May 23, 1802; by Wallis on April 15, 1826; by

[j] Laplace has demonstrated by the theory of gravitation that if this relation be once approximately begun, it will *always* last.

[k] *Acta Soc. Upsal.*, p. 41. 1743.

[l] *Ast. Nach.*, vol. lviii. No. 1377. Aug. 25, 1862.

[m] *Sol. Syst.*, p. 98.

[n] *Opticks*, p. 271.

Dawes and W. Griesbach on Sept. 27, 1843. Dawes published in 1862 an account of his observations [o]. Jupiter's (apparent) deprivation of its satellites lasted about 35^m. A repetition of this curious phenomenon occurred on Aug. 21, 1867, when the planet was apparently without satellites projected on the sky for $1\frac{3}{4}^h$.

The satellites appear to vary in brilliancy in a way wholly inexplicable. I have already stated that **III** is commonly the *brightest*; but Maraldi and Bond have seen the contrary. On the whole, perhaps, we are justified in saying that the *faintest* is **IV**; but the lustre of this is irregular: in 1711 Bianchini and another, and on June 13, 1849, Lassell, saw it so feeble as to be almost invisible, whilst Webb has repeatedly seen it surpass **III**. This observer writes—"Spots . . . may easily cause this variable light; but a stranger anomaly has been perceived,—the discs themselves do not always appear of the same size, or form. Maraldi noticed the former fact in 1707, W. Herschel 90 years afterwards too inferring also the latter; and both have been since confirmed. Beer and Mädler, Lassell, Secchi and Buffham have sometimes seen the disc of **II** larger than **I**; and Lassell, and Secchi and his assistant, have distinctly seen that of **III** irregular and elliptical; and according to the Roman observers the ellipse does not always lie the same way: Buffham has often found **IV** the smallest of all, and irregular-looking. Phenomena so minute hardly find a suitable place in these pages, but they seem too singular to be omitted; and in some cases, possibly, small instruments [?] may just indicate them; at least, with an inferior fluid achromatic reduced to 3 inches aperture I have sometimes noticed differences in the size of the discs which I thought were not imaginary [p]."

Sir W. Herschel, by attentive and prolonged observation, was led to infer that each of the satellites rotated on its axis in the same time that it made a synodical revolution round its primary, thus presenting an analogy to the case of our Moon. The immediate reason which induced this conclusion was a belief that the variation in their brilliancy always recurred in nearly the same positions of the satellites with respect to Jupiter and the Sun, which supposition had previously presented itself to the mind of Cassini [q]. But modern observations do not harmonise with these

[o] *Month. Not.*, vol. xxii. p. 292. June 1862.

[p] *Celest. Objects*, p. 146.

[q] *Mém. Acad. des Sciences*, vol. i. p. 266.

statements; that is to say, we are not entitled to affirm now that peculiarities in the appearances of the satellites correspond with definite orbital positions. On the contrary, the peculiarities observed are not governed by any known law of time or place whatever.

Arago thus sums up Sir W. Herschel's photometric deductions. "The Ist satellite is at its maximum brightness when it attains the point of its orbit which is almost midway between the greatest Eastern elongation and its conjunction. The brightest side of the IInd satellite is also turned towards the Earth when that body is between the greatest Eastern elongation and conjunction. The brightness of the IIIrd satellite attains 2 maxima in the course of a revolution, namely at the 2 elongations. The IVth shines with a bright light only a little before and a little after opposition [r]."

Various observers have assigned colours, or rather tinges of colour, to the different satellites, but the results are not sufficiently of accord to be worth citing.

Eclipses as viewed *on* Jupiter take place on a grand scale; for in consequence of the small inclinations of the orbits of the satellites to the planet's equator and the small inclination of the latter to the ecliptic, all the satellites, the IVth excepted, are eclipsed some time in every revolution; so that a spectator on Jupiter might witness during the Jovian year 4500 eclipses of the Moon (Moons) and about the same number of the Sun.

Soon after their discovery it suggested itself to the reflecting mind of Galileo that eclipses of the satellites of Jupiter might be made useful for determining the longitude. Regarding eclipses as instantaneous phenomena visible at the same moment in every place which has the planet above its horizon, it is clear that a comparison of observations recorded in 2 local times would afford data for determining the difference of time (longitude) between the places to which the times belong. Eclipses accurately *predicted* for one meridian when observed under another one would afford a still more advanced means of ascertaining the difference of longitude between them. These eclipses could be predicted if sufficiently accurate tables of the satellites were in existence; but at sea, where the problem has chiefly to be solved, they cannot be observed with the

[r] *Pop. Ast.*, vol. ii. p. 549. Eng. ed.

most refined accuracy, and on land some difficulties present themselves; so the method to some extent breaks down, and is only available where very rough approximations will suffice.

It was to observations of the satellites of Jupiter, and Römer's discussion of them in 1675, that we owe the discovery that light is not propagated instantaneously through space[s]. It was found that the calculated times of the eclipses did not correspond with the observed times, and that the difference was a quantity constantly affected by opposite signs of error according as Jupiter was in perigee or apogee. In the former case the eclipse always occurred before the calculated time; in the latter, always after it. The regularity with which these anomalies showed themselves led Römer to suspect that they had their origin in the variations which occurred in the distance of Jupiter from the Earth: that as this distance increased or diminished so a longer or a shorter period was requisite for light to traverse the space between the 2 planets. Assuming from the data in his possession that light travelled at the rate of 192,000 miles per second, and required $16\frac{1}{2}^{m}$ to traverse the diameter of the Earth's orbit, and applying this (as yet hypothetical) conclusion to the eclipses in the form of a trial-correction, Römer promptly obtained proofs of the accuracy of his reasoning. The modern experiments of Fizeau have given a result but slightly differing in amount from Römer's, namely, 194,000 miles per second[t].

Like most new discoveries Römer's did not, when promulgated, find favour in the scientific world, and many years elapsed ere it was generally accepted.

The mass of Jupiter has never been a very doubtful quantity, all the values of it being much more in accord with one another than is usually the case. Laplace, from Pound's observations of the IVth satellite, placed it at $\frac{1}{1067}$; Bouvard, from the perturbations of Saturn, at $\frac{1}{1070}$; Nicolai, from the perturbations of Juno, at $\frac{1}{1053 \cdot 92}$; Encke, from the perturbations of Vesta, at $\frac{1}{1050}$; and

[s] *Opere di Galileo*, vol. ii. p. 33. Padua ed., 1744.

[t] In consequence of the reduction in the received value of the Sun's parallax a reduction in the velocity of light by several thousands of miles per second must be assumed, and singularly enough some experiments of Foucault's *made before the parallax question came up for general discussion* pointed to the same conclusion. The value for the velocity of light now generally accepted is about 185,500 miles per second. (Cornu.)

from perturbations of the Comet bearing his name, at $\frac{1}{1054}$; Santini at $\frac{1}{1050}$; Bessel at $\frac{1}{1047.87}$; Airy, from motions of the satellites, at $\frac{1}{1046.77}$; Krüger, from observations of Themis, at $\frac{1}{1047.54}$; Jacob, from the motions of the satellites, at $\frac{1}{1047.54}$; and Möller, from the motions of Faye's Comet, at $\frac{1}{1047.78}$. Any one of the three last values may be taken to be substantially exact.

"The most ancient observation of Jupiter which we are acquainted with is that reported by Ptolemy in Book X. chap. iii. of the *Almagest*, and considered by him free from all doubt. It is dated in the 83rd year after the death of Alexander the Great, on the 18th of the Egyptian month *Epiphi*, in the morning, when the planet eclipsed the star now known as δ Cancri. This observation was made on Sept. 3, B.C. 240, about 18^h on the meridian of Alexandria."

The tables of Jupiter used till recently were those of A. Bouvard, published in 1821, but the new and far superior Tables of Le Verrier have superseded them [u]. For the satellites, Damoiseau's Tables (published in 1836) are employed. As regards the satellites there is room for much improvement in the tables at present employed. They fail to give results characterised by the precision which modern science demands.

[u] These tables were employed for the first time in England in the preparation of the *Nautical Almanac* for 1878, issued in 1874.

CHAPTER XII.

SATURN[a]. ♄

Period, &c.—Figure and Colour of Saturn.—Belts and Spots.—Probable atmosphere.—Observations of Galileo, and the perplexity they caused.—Logogriph sent by him to Kepler.—Huyghens's discovery of the Ring.—His logogriph.—The bisection of the Ring discovered by the brothers Ball.—Sir W. Herschel's Doubts.—Historical epitome of the progress of discovery.—The "Dusky" Ring.—Facts relating to the Rings.—Appearances presented by them under different circumstances.—Rotation of the Ring.—Secchi's inquiries into this.—The Ring not concentric with the Ball.—Measurements by W. Struve.—Other measurements.—Miscellaneous particulars.—Ring probably fluid.—O. Struve's surmise about its contraction.—Irregularities in the appearances of the ansæ.—Rings not bounded by plane surfaces.—Mountains suspected on them.—An atmosphere suspected.—Saturn attended by 8 Satellites.—Table of them.—Physical data relating to each.—Elements by Jacob.—Transits of Titan.—Peculiarity relative to the illumination of Iapetus.—Mass of Saturn.—Ancient observations.—Saturnian astronomy.

INFERIOR in size to Jupiter alone, Saturn may fairly be pronounced to be the most interesting member of the solar system. It revolves round the Sun in $10759{\cdot}2^{d}$ or $29{\cdot}45^{y}$ at a mean distance of 872,134,000 miles, which an orbital eccentricity of 0·056 may increase to 921,105,000 or diminish to 823,164,000 miles. Its apparent diameter varies between $14{\cdot}6''$ in conjunction, and $20{\cdot}3''$ in opposition, and its real (equatorial) diameter may be taken at 71,904 miles. Its polar compression is larger than that of any other planet, Jupiter not excepted: but it is usually less noticeable than that of Jupiter because the ring distracts the eye. Sir W. Herschel's value of the compression is $\frac{1}{10{\cdot}34}$; Bessel's $\frac{1}{10{\cdot}19}$; the Rev. R. Main's $\frac{1}{9{\cdot}22}$[b]; and Hind's $\frac{1}{9{\cdot}02}$.

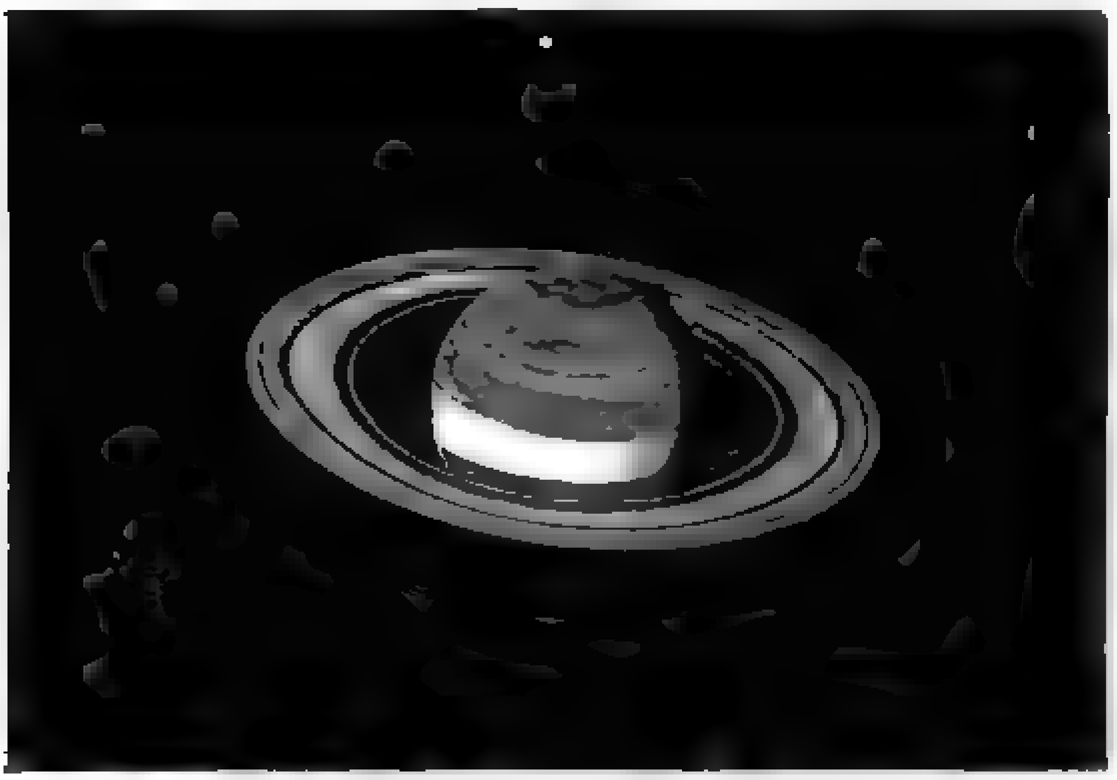
[a] For drawings, &c. of Saturn, see *Annals of Harvard Coll. Obs.*, vol. ii. (120 drawings by the Bonds); *Ast. Nach.*, vol. xxviii. No. 650, Nov. 1848 (J. F. J. Schmidt); *Ibid.*, vol. xxxix. No. 929, Jan. 8, 1855 (Secchi); *Mem.* R.A.S., vol. iv. p. 383 (Kater); *Ibid.*, vol. xxi. p. 151 (8 figs. by Lassell); *Month. Not.*, vol. xi. p. 23 (Dawes and Lassell); *Ibid.*, vol. xiii. p. 16 (Dawes); *Ibid.*, vol. xiv. p. 17 (Dawes); *Ibid.*, vol. xv. p. 79 (Dawes); *Ibid.*, vol. xvi. p. 120 (one fig. by Jacob); *Ibid.*, vol. xviii. p. 75 (abstract of *Harvard Obs.*); and vol. xxii. p. 89 (two figs. by Jacob); *Student*, vol. ii. p. 240 (Browning).

[b] See *Month. Not.*, vol. xiii. p. 79, Jan. 1853, for others, and same vol., p. 152, for a note by the Rev. R. Main: an important memoir by the same observer appears in *Mem.* R.A.S., vol. xviii.

Saturn has no *perceptible* phases. The maximum defalcation of light under extreme circumstances is so small that the maximum breadth of the shaded area can hardly be $\frac{1}{10}$th of a second of arc—a quantity inappreciable.

The figure of Saturn is now quite understood to be that of an oblate spheroid, but at one time considerable doubt existed about the matter in consequence of Sir W. Herschel having advanced the opinion, from observations made in April 1805, that the planet was compressed at the equator as well as at the poles; or, as it is generally phrased, that it resembled a parallelogram with the corners rounded

Fig. 55.



Saturn, March 27 and 29, 1856. (*De La Rue.*)[c]

off, so as to leave both the equatorial and the polar regions flatter than they would be in a regular spheroidal figure. This opinion, never received with much favour (though *not* entirely unconfirmed by later observers), is now almost universally repudiated, chiefly owing to the micrometric measurements performed by Bessel in 1833 and by Main in 1848. Some optical illusion was probably at the foundation of it, though it is right to say that the notion is believed in to this day by some persons, and ascribed to an actual

[c] The dark ring C is very decidedly *too narrow* as indicated in the engraving.

upheaval of the planet's surface recurring from time to time and due to quasi-volcanic causes. It must also be added, that (as in the case of Jupiter) we only see the outline of Saturn's *atmosphere* and not that of the solid (or fluid) body of the planet itself.

Belts exist on Saturn resembling those of Jupiter, but they are very much fainter. They are probably of the same physical character. It is Lassell's opinion that, taking the planet as a whole, it may be said that the south pole is generally darker than the north pole and more blue in tinge. The dark belts on the planet are often thought to exhibit a greenish hue. The planet's ordinary colour is yellowish white, the belts inclining to grayish white. Browning finds that large apertures bring out the existence of considerable diversities of colour on Saturn. Any first-class telescope of 4 inches aperture will exhibit the marked distinction between the yellow tint of Saturn's globe and the silvery or bluish white hue of ring **B**.

The belts of Saturn differ from those of Jupiter in the respect that they exhibit at times a sensible curvature, whilst those of Jupiter are rectilinear. Hence we draw the conclusion that if the belts of Saturn are parallel to the planet's equator (as probably is the case), then the plane of this equator must make a rather considerable angle with the ecliptic. A quintuple belt furnished Sir W. Herschel with the means of determining the period of the planet's axial rotation, which he fixed at $10^h\ 16^m\ 0{\cdot}44^s$, from observations extending over 100 rotations between Dec. 4, 1793 and Jan. 16, 1794[d]. Subsequently he made the period to be $10^h\ 29^m\ 16{\cdot}8^s$. Schröter's results exceed this, but contradict one another considerably. His highest result was as much as 12^h.

Spots on Saturn are very rare. The instances on record hardly number a dozen.

Sir W. Herschel considered that he had obtained decided indications of the existence of an atmosphere on Saturn: the satellites when undergoing occultation never disappeared instantaneously, but seemed to hang on the planet's limb, in one case for as long as 20^m. Such a retardation would imply a horizontal refraction of $2''$, but no confirmation of this has been obtained by any subsequent observer. The same observer found other proofs of an atmo-

[d] *Phil. Trans.*, vol. lxxxiv. p. 62. 1794.

sphere: an examination of the polar regions on various occasions shewed that according as they were turned towards or from the Sun a difference of hue was perceptible, which might reasonably be supposed to be due to snow in those regions melting under the Sun's rays, and accumulating in the absence of those rays, as has been explained when speaking of Mars.

When Saturn was first telescopically examined by Galileo, he noticed that it presented a very oval outline, which in his opinion gave the notion of a large planet having on each side of it one smaller one. He added, that with telescopes of superior power, the planet did not appear triple, but exhibited an oblong form, somewhat like the shape of an olive[e].

Continuing his observations, the illustrious astronomer was not long in noticing that the two (supposed) bodies gradually decreased in size, though still in the same position as regards their primary[f], until they finally disappeared altogether[g]. Galileo's amazement at this was unbounded, and his third letter to Welser, dated Dec. 4, 1612, in which he expresses his feelings on the subject, is still extant. He remarks:—

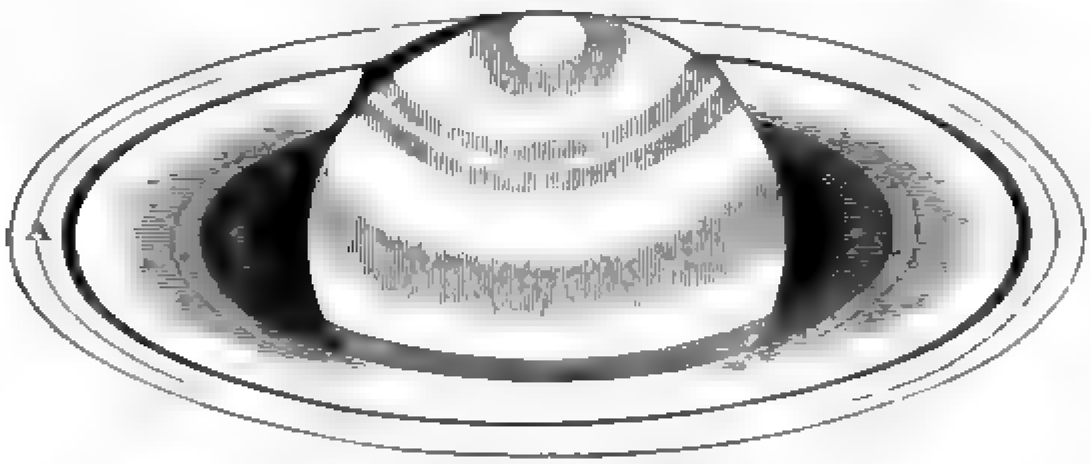
"What is to be said concerning so strange a metamorphosis? Are the two lesser stars consumed after the manner of the solar spots? Have they vanished or suddenly fled? Has Saturn, perhaps, devoured his own children? Or were the appearances indeed illusion or fraud, with which the glasses have so long deceived me, as well as many others to whom I have shewn them? Now, perhaps, is the time come to revive the well-nigh withered hopes of those who, guided by more profound contemplations, have discovered the fallacy of the new observations, and demonstrated the utter impossibility of their existence. I do not know what to say in a case so surprising, so unlooked for, and so novel. The shortness of the time, the unexpected nature of the event, the weakness of my understanding, and the fear of being mistaken, have greatly confounded me[h]." Galileo was so disgusted that he entirely abandoned observations of Saturn.

[e] *Opere di Galileo*, vol. ii. p. 41. Padua ed., 1744.

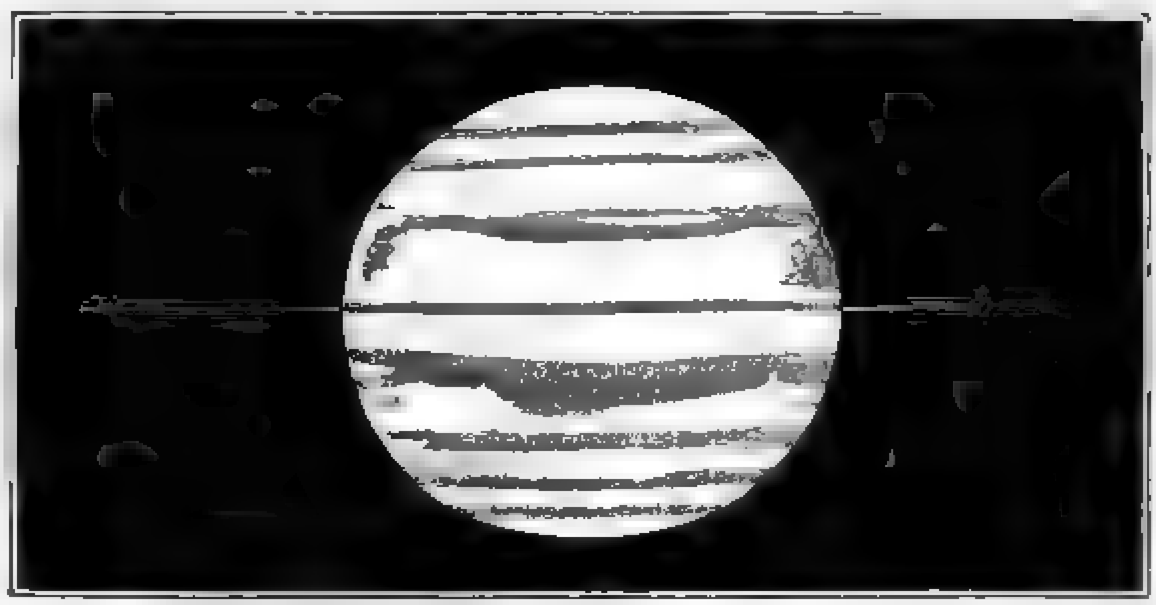
[f] *Ibid.*

[g] A nodal passage took place in Dec. 1612, when of course Saturn would in such a telescope as Galileo's appear to be destitute of all appendages whatever.

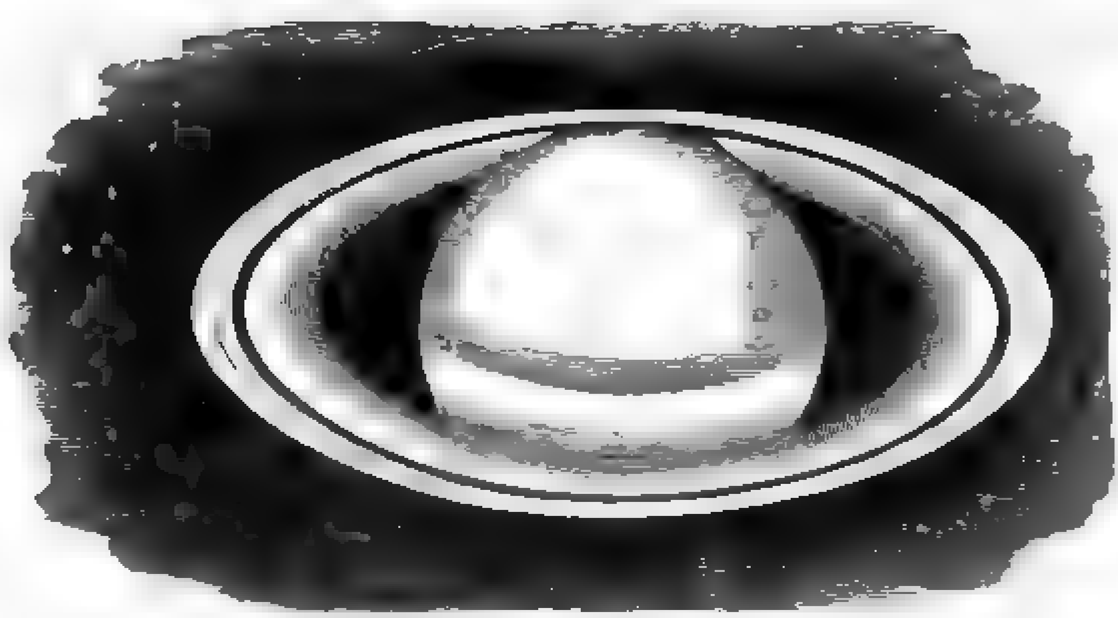
[h] *Opere di Galileo*, vol. ii. p. 152. Padua ed., 1744.



1853 : Nov. 2. (*Dawes.*)



1848. (*W. C. Bond.*)



1856. Jan. 8. (*Jacob.*)

SATURN.

The original discovery was announced to Kepler in the following logogriph[i] :—

smaismrmilmepoetalevmibvnenvgttaviras;

which, being transposed, becomes—

altissimvm planetam tergeminvm observavi;

"I have observed the most distant planet to be tri-form."

As time wore on, more correct ideas were obtained of the phenomenon, which gradually came to be looked upon as due to the existence of two ansæ, or handles, to the planet, though the cause of their disappearance from time to time was yet unexplained. It was not till after the lapse of nearly 50 years that the true cause of the appearance seen by Galileo and others became known. C. Huyghens was the discoverer, and he intimated his discovery in the following logogriph[k] :—

aaaaaaa ccccc d eeeee g h iiiiiii llll mm nnnnnnnnn oooo pp q rr s ttttt uuuuu;

which letters, when placed in their proper order, give—

annulo cingitur, tenui, plano, nusquam cohaerente, ad eclipticam inclinato;

"The planet is surrounded by a slender flat ring inclined to the ecliptic, but which nowhere touches the body of the planet[l]."

It must not be supposed that this discovery was the result of a chance inspiration. On the contrary, Huyghens seems to have spent several years in scrutinising Saturn before he finally decided that the theory of a ring round the planet was the only one which would reconcile the various observed facts.

With the view of commending his hypothesis to the attention of astronomers, Huyghens ventured to predict that in the month of July or August 1671 the planet would again appear round; and in this he was nearly correct, for Cassini, watching the disappearance of the ring, found the planet presenting this aspect in May 1671, or within 2 months of the time foretold by Huyghens.

[i] *Opere di Galileo*, vol. ii. p. 40. Padua ed., 1744.

[k] *De Saturni Luna Observatio Nova.* Hagæ, 1656. Followed in 1659 by detailed particulars in the *Systema Saturnium.*

[l] T. Maurice (*Indian Antiquities*) gives an engraving of *Sani*, the Saturn of the Hindûs, from an image in an ancient pagoda. A circle is formed around him by the intertwining of two serpents; whence the writer infers that, by some means or other, the existence of Saturn's ring may have been known in remote ages. The same thing is observable in Assyrian sculptures; but it must in candour be added that this ring-surrounded Deity possessed a signification (impossible to be alluded to here) in the ancient Phallic worship.

As advances have been made in the manufacture of telescopes, so our knowledge of the Saturnian system has been increased. On Oct. 13, 1665, within a very few years of Huyghens's discovery, 2 English observers of the name of Ball, residing at Minehead in Somersetshire, discovered that what Huyghens saw as one ring was in reality a combination of two, lying concentrically, one within the other. The honour of this discovery was conceded to Cassini (who ascertained the fact independently in 1675) till Hind in 1852 called attention to the observations of the English amateurs, which he found in the *Philosophical Transactions* [m]. Sir W. Herschel was for a long time very unwilling to allow that this division was actually such in fact; and he did not become convinced until he had executed a very protracted series of observations extending over several years. He coupled his acceptance of the division with a strong assertion that it was the only one that existed.

But we have now certain knowledge of the existence of more than 2 rings, and the system must be described as a *multiple* one.

It is stated by Lalande [n] that Short, the celebrated optician, perceived several concentric streaks on the outer ring. It is not known that Short left any record of his own relating to this.

Between June 19 and 26, 1780, Sir W. Herschel [o] perceived a slight dark streak close to the interior edge of the western ansa. It had disappeared on June 29, and no corresponding appearance at all was seen on the other ansa.

In Dec. 1823 M. Quetelet, at Paris, with a Cauchoix achromatic of 10 inches aperture, thought he saw a division in the exterior ring [p].

On Dec. 17, 1825, Capt. Kater, with a 6-inch Newtonian reflector, perceived in the exterior ring numerous black streaks very close to each other [q]. On Jan. 16, 1826, with another telescope, the same observer saw similar markings, but as on Jan. 22, 1828 none whatever could be perceived, he concluded that they had no permanent existence.

On April 25, 1837, Encke [r], at Berlin, assured himself of the existence of a division in the exterior ring; on May 28 following

[m] *Phil. Trans.*, vol. i. p. 152. 1666.

[n] *Astronomie*, vol. iii. Paragraph 3228. 2nd ed. Paris, 1771.

[o] *Phil. Trans.*, vol. lxxxii. p. 8. 1792.

[p] *Mem.* R.A.S., vol. iv. p. 388. 1831.

[q] *Mem.* R.A.S.. vol. iv. p. 384. 1831.

[r] *Trans. Berl. Acad.*

he was able to procure measurements which shewed that the old ring was unequally divided, the wider portion lying outermost.

On May 29, 1838, Di Vico, at Rome, perceived not only this division in the exterior ring, but two similar divisions in the interior.

On Sept. 7, 1843, Lassell and Dawes[s] saw a decided division in the exterior ring *at both ends*, but placed it near the *outermost* edge, thereby failing to agree with Encke's measurements of 1837.

This subdivision of the exterior ring is now generally accepted[t], and De La Rue's beautifully executed engraving (indifferently reproduced in the woodcut, Fig. 55, p. 132) conveys a good idea of it.

The discovery of another curious and interesting feature has now to be dealt with. In 1838 Galle, in examining Saturn, noticed a gradual shading off of the interior bright ring towards the ball. He published a note of this observation, but little or no attention seems to have been paid to it[u]. On Nov. 11, 1850, G. P. Bond perceived a luminous appearance between the ring and the planet: subsequent observations by himself and his father shewed that this luminous appearance was neither more nor less than another ring. Neither of these observers could satisfactorily determine whether this dusky ring (as it soon came to be called) was actually in contact with the interior bright ring, but they thought it was not[v]. Before the arrival of the American mail conveying intelligence of this new ring, Dawes had found it. On Nov. 29 he entered in his journal the following remark: "After a few seconds of uncommonly sharp vision, I involuntarily exclaimed, 'Obvious.' There is a *shading*, like *twilight*, at the inner portions of the inner ring[x]." This acute observer was not long in ascertaining the annular character of the "shading," and moreover he found (as did O. Struve also) that the dusky ring was occasionally divided into 2 or more

[s] *Month. Not.*, vol. vi. p. 12.

[t] Jacob on the contrary expressed in unequivocal terms his conviction that the black mark or so-called division in the exterior ring was merely a *depression*. He was confident that it reflected the planet's shadow, shewing an apparent projection, such as every shadow falling on a groove has. (*Month. Not.*, vol. xvi. p. 126, March 1856; vol. xvii. p. 174, April 1857.) Hippisley and Watson disbelieve in a division, and adhere to the opinion that the mark is merely a mark, and that its breadth varies. (*Month. Not.*, vol. xiv. p. 163, March 1854; vol. xvi. p. 152, April 1856.)

[u] *Trans. Berl. Acad.*, 1838. See also *Ast. Nach.*, vol. xxxii. No. 756. May 2, 1851; and *Month. Not.*, vol. xi. p. 184. June 1851.

[v] *Mem. Amer. Acad. of Arts and Sciences*, vol. v. (N. S.) p. 111. 1855.

[x] *Month. Not.*, vol. xi. p. 23. Dec. 1850.

concentric rings. This fact is not indicated in De La Rue's engraving, but the transparent nature of the entire ring is well shewn. On Dec. 3, Lassell, while on a visit to Dawes, saw "something like *a crape veil* covering a part of the sky within the inner ring:" this observation was made in consequence of a hint given by Dawes as to what he himself had seen[y].

It has been thought that the dusky ring is wider and less faint than formerly. On March 26, 1863, Carpenter found it to be "nearly as bright as the illuminated ring," so much so that it "might easily have been mistaken for a part of it[z]."

Figs. 61–2 on Plate IX. relate to a very interesting observation made by Wray on Dec. 26, 1861. He saw—"A prolongation of very faint light stretched on either side from the dark shade on the ball, overlapping the fine line of light formed by the edge of the ring, to the extent of about one-third its length, *and so as to give the impression that it was the dusky ring, very much thicker than the bright rings,* and seen edgewise projected on the sky[a]."

The transparency of the dusky ring was not ascertained till 1852; Jacob, Dawes, and Lassell share this discovery between them[b].

Having said this much on the history of these discoveries, some facts connected with the rings must now be set out. Their true form is no doubt circular, or nearly so; but as we always see them foreshortened, they appear more or less oval when the Earth is above or below the plane of the rings, but when we are nearly in the plane they appear as a single straight line, or something like it. When we are exactly in the plane they disappear altogether, except in very large telescopes. The diagram Fig. 59 will make this sufficiently clear. In the true position of the rings during Saturn's revolution round the Sun there is no change: they remain continually parallel to each other.

[y] A passage in *Phil. Trans.*, 1723, by Hadley, almost leads one to infer that he had seen the dusky ring, though without being able to make up his mind as to what it was. Hind, in *Month. Not.*, vol. xv. p. 32, Nov. 1854, expresses his belief that a record of Picard's will fairly bear the interpretation that he saw the dusky ring, with the like comprehension as Galle, on June 15, 1673.

[z] *Month. Not.*, vol. xxiii. p. 195. April 1863.

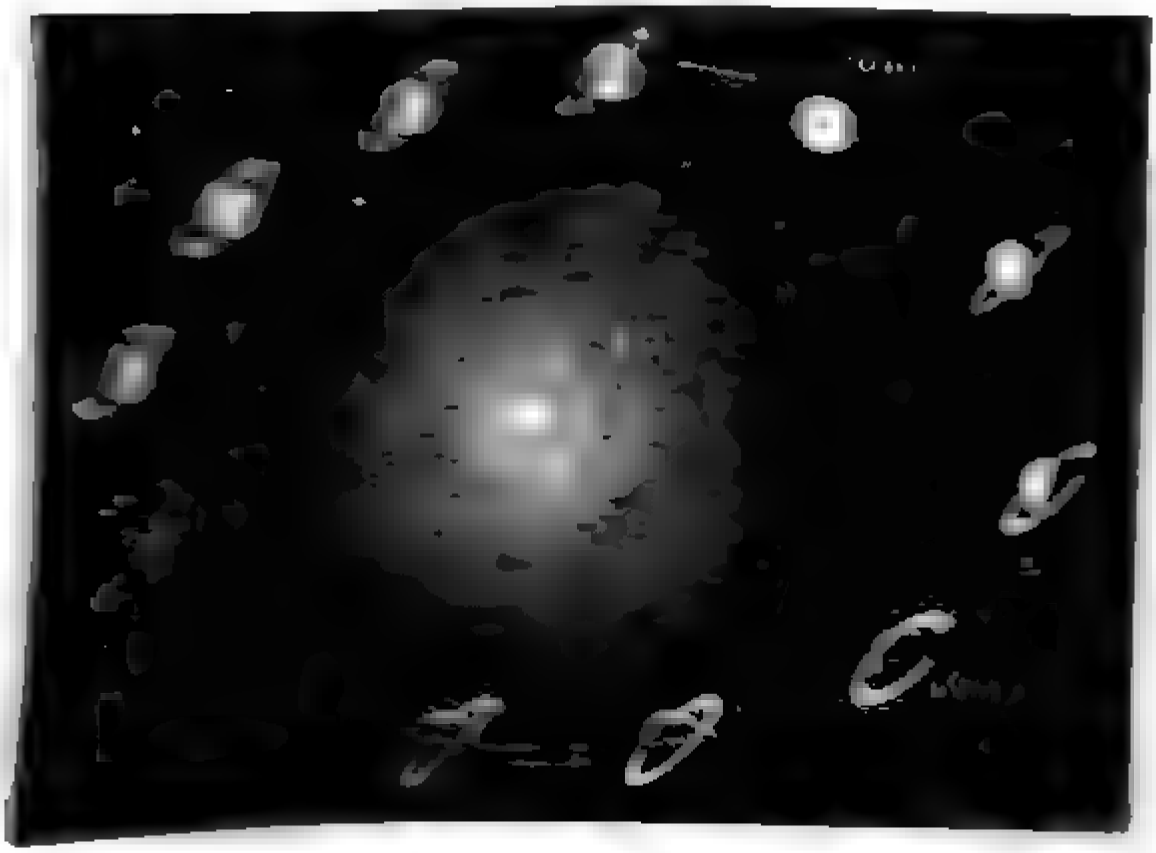
[a] *Month. Not.*, vol. xxiii. p. 86. Jan. 1863.

[b] Perhaps this sentence requires to be qualified, for Galle, in his drawing, represents the planet seen through the ring; but it must be remarked that he did not know he was looking at a *ring*, and only intended to draw what was (and readily might be) taken for a belt on the planet of more than ordinary intensity of shade.

[illegible] to the [illegible] and [illegible] 43 [illegible] being the place of the [illegible] the ascending node. Ac- [illegible] the node of the ring referred to [illegible]

[illegible] the Earth [illegible] the Sun, the phenomena [illegible] the rings of Saturn are much the same, but [illegible] Earth [illegible] the inclination of which differs

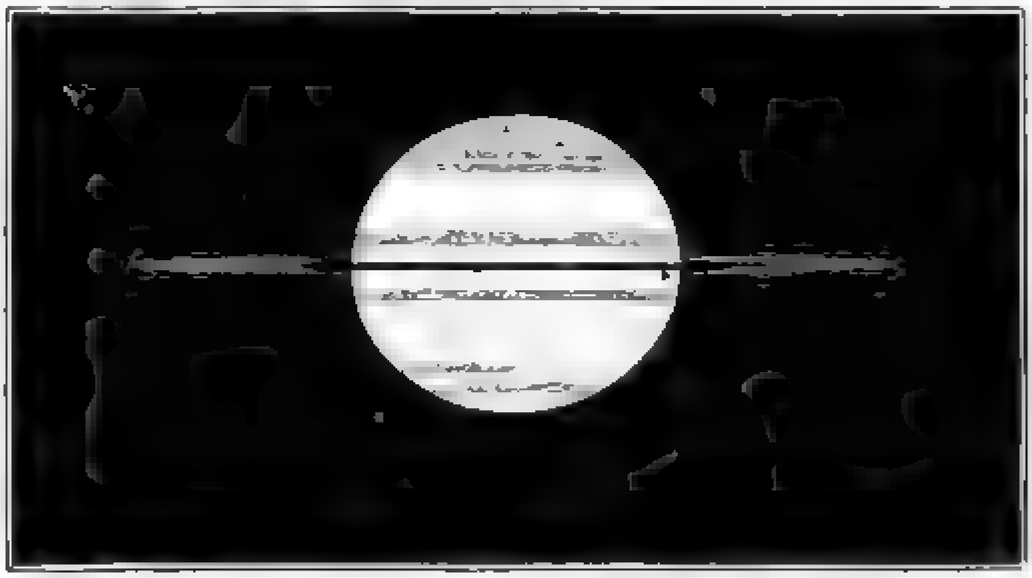
Fig. [illegible]



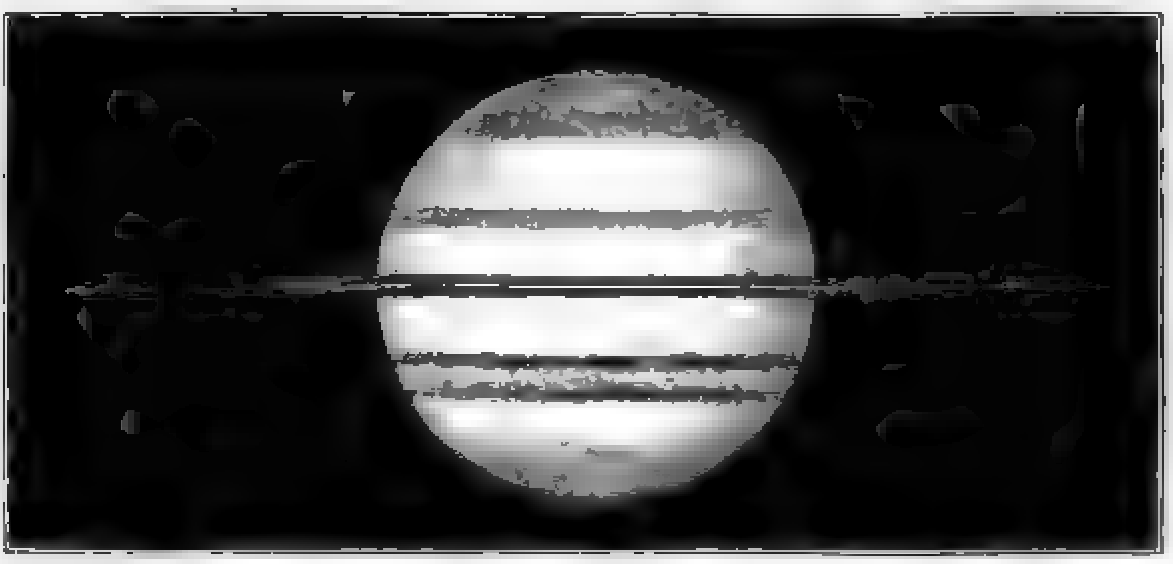
[illegible] Rings.

[illegible] of Saturn gives rise to certain phases in the [illegible] not be witnessed by an observer placed on the [illegible] usually happens that there are 2, if not 3[*], disap- [illegible] at the time of the planet's arrival at the nodes. The [illegible] ring may not pass through the Earth and Sun at [illegible] time, but the ring may be invisible under both con- [illegible] because its edge only will be directed towards us. It is [illegible] invisible when the Earth and Sun are on opposite sides of

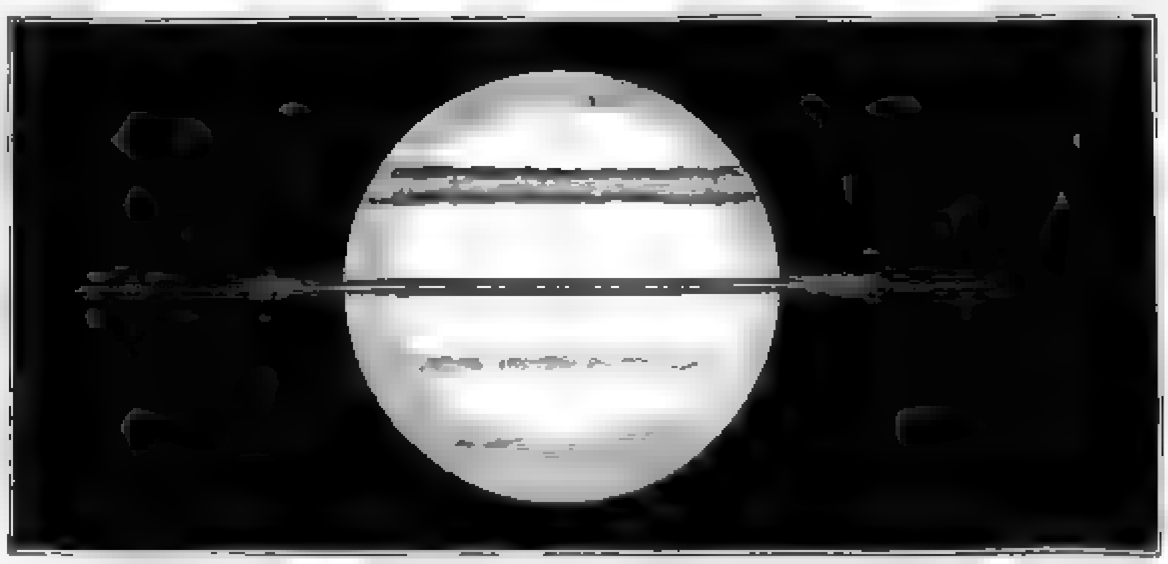
* There can really never be more than two disappearances.



1861 : November. (*Anon.*)



1861 : Dec. 26. (*Wray*)



1862 : Jan. 5 (*Wray*)

SATURN.

its plane—a state of things that may continue a few weeks: in this case we have the dark surface turned towards our globe. In very powerful telescopes it has been found that the disappearance of the ring is complete under the latter condition; it has, however, been perceived as a faint broken line of a dusky colour, not only when the Sun is in its plane, but likewise when its edge is directed to the Earth. Our remarks must be considered as applying to observations with telescopes in common use." The foregoing is chiefly from Hind[a]; a fuller account is given by Sir John Herschel[b], but it is beyond my purpose to go further into this matter.

Saturn's year being 29.458ʸ, the half of this, or 14.729ʸ, will be the average time elapsing between 2 nodal passages. Such a passage took place in 1862. The Southern surface of the ring had been then visible for 14.7ʸ.

In 1855 the planet was in 77.5° of longitude, one of the 2 points at which the greatest opening of the rings occurs. From that time the breadth diminished till Nov. 23, 1861, when the motions of the planet and of the Earth again brought the ring edgewise to the Earth and caused it to disappear, the Sun being South of the plane, and the Earth crossing to the North. On Jan. 31, 1862, the Sun, passing through the plane of the ring, began to illuminate its Northern surface, and the Earth being also on that side the ring reappeared. On May 17 the Earth went to the South, and the Sun remaining on the North, a second disappearance took place. The ring remained invisible, in consequence of presenting its unilluminated side to us, till Aug. 12, 1862, when the Earth once more passing through the plane of the ring to the North, brought the Northern side into view—a state of things which will last till 1877. The last greatest opening out of the ring occurred in Aug. 1869, the planet being in longitude 257.5°: the next will occur in June 1885, with the planet in longitude 77.5°.

It will be seen from De La Rue's drawing of 1856 [Fig. 55], and from others taken at the epoch of maximum breadth, that the ball is at such times entirely encompassed by the ring, and that thus the outline of the whole system is a perfect ellipse: this state of

[a] Solar System, p. 103. [b] *Outlines of Ast.*, p. 343 *et seq.*

things always lasts for several months. The ring of Saturn is most open when the planet is in either Gemini or Sagittarius.

By a careful examination of the ring Sir W. Herschel ascertained that it revolves round the ball in $10^h\ 32^m\ 15^s$—a period not greatly in excess of that of the planet's own axial rotation: the direction is the same in both cases. There are, however, great difficulties in the way of admitting this rotation [f].

In 1854–5–6, Secchi executed numerous measures of the rings, but they exhibited considerable discordances. He afterwards found that whilst those of 2 consecutive days did not harmonise, those of 3 and 9 days did; and the idea then occurred to him that the results might be explained by supposing the ring to be elliptical, presenting sometimes its longer, sometimes its shorter diameter. He failed to reconcile Herschel's period of rotation with his own observations, but found that a period which corresponds with that which a satellite placed on the margin of the ring would have (namely, $14^h\ 23^m\ 18^s$) would satisfy them [g].

Some years ago O. Struve introduced a system for conveniently distinguishing the rings from each other, in writing and speaking, which is now generally adopted. He called the exterior bright ring **A**, the interior bright ring **B**, and the dusky one **C**. When reference is made to the whole system it is very usual to say 'ring,' in the singular number, no one ring in particular being thereby meant.

The ring is not concentric with the ball. Gallet of Avignon announced this in 1664, placing the ball nearer to the East ansa.

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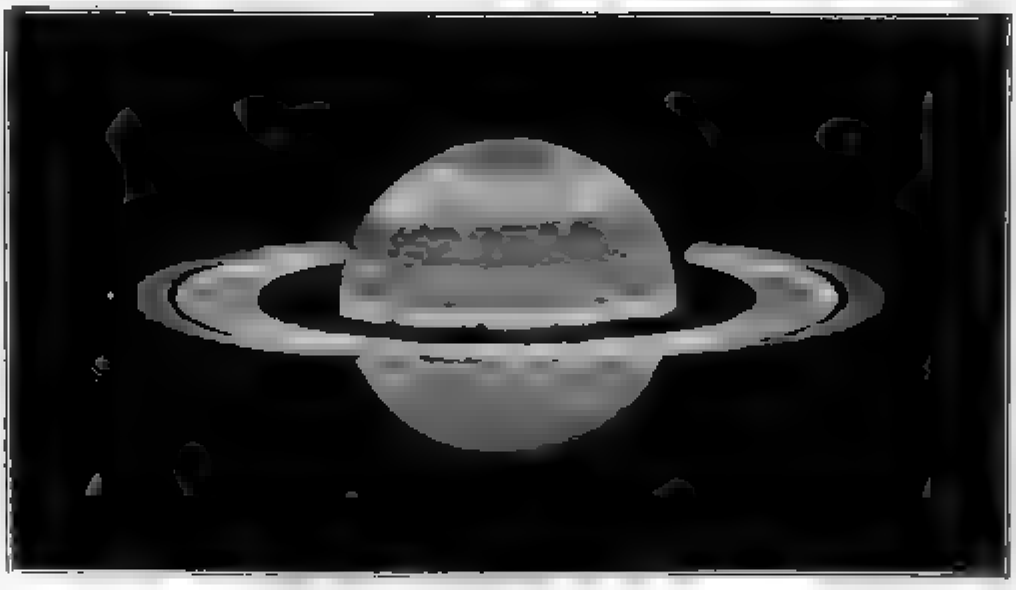
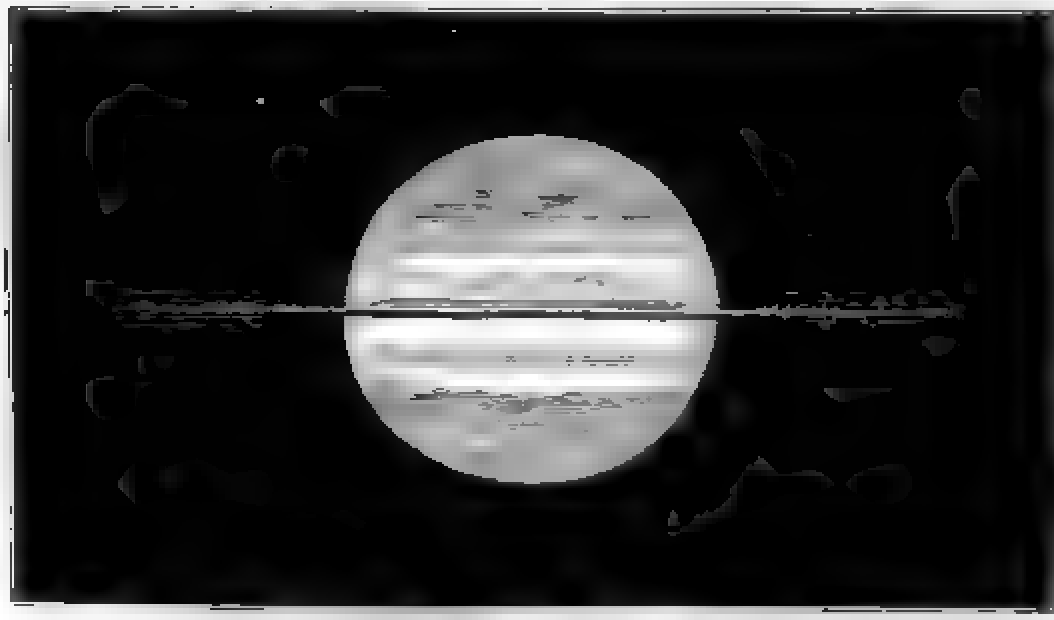
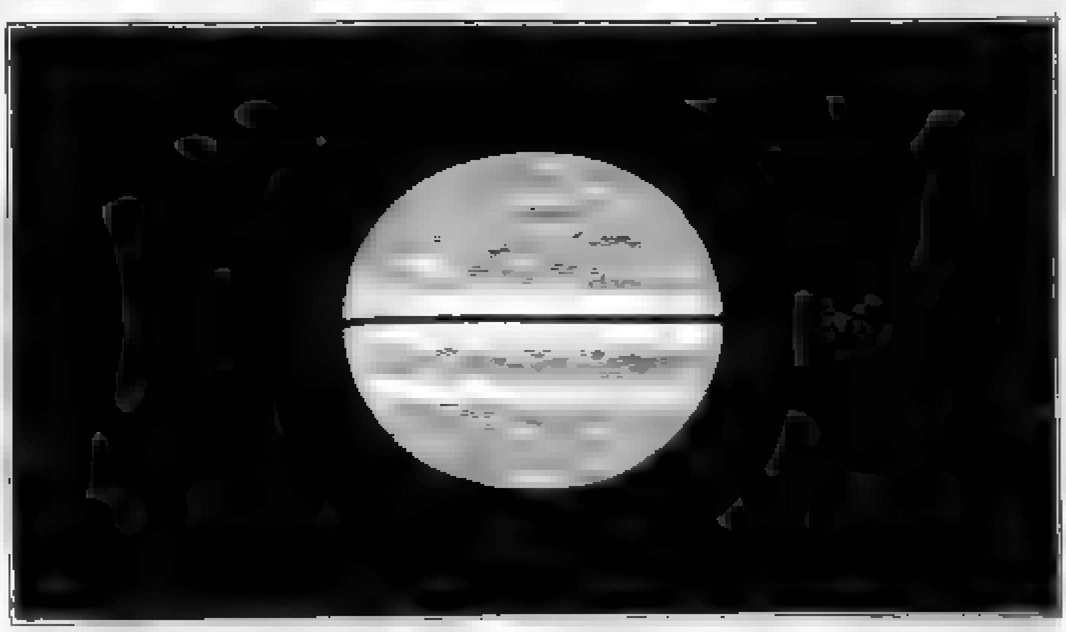
[g] *Month. Not.*, vol. xvi. p. 52. Jan. 1856.



1861 April 7 (*De La Rue.*)



1861 Nov 12. (*Jacob.*)



1861 Dec 4. (*Jacob.*)

SATURN.

The following angular measurements, reduced to the mean distance of the planet (but calculated on the old and erroneous solar parallax of 8·5776″), are by the same observer :—

	″		English Miles.
Outer diameter of exterior ring	40·095	=	169,530
Inner diameter "	35·289	=	149,210
Breadth "	2·403	=	10,160
Outer diameter of interior ring	34·475	=	145,768
Inner diameter "	26·668	=	112,758
Breadth "	3·903	=	16,503
Interval between the two	0·408	=	1,725
Distance of ring from ball	4·339	=	18,346
Equatorial diameter of ball	17·60	=	74,417

The measures of De La Rue[h], Main[i], and Jacob[k] are appended for comparison[l] :—

	De La Rue.	Main.	Jacob.
	″	″	″
Outer diameter of exterior ring	39·83	39·73	39·99
Inner diameter "	35·33		35·82
Breadth "	2·25		2·08
Outer diameter of interior (middle) ring	33·45		34·85
Inner diameter " "	26·91	27·65	26·27
Breadth " "	3·27		4·29
Interval between the two	0·94		0·48
Distance of ring from ball	4·62	5·07	4·16
Equatorial diameter of planet	17·66	17·50	17·94

There are some particulars relating to the rings which cannot well be classified. Sir J. Herschel estimated their thickness at not more than 250 miles; G. P. Bond cut this down to 40 miles. Peirce thought that there were good grounds for supposing them to be fluid rather than solid; but the opinion which meets with most favour now is that they are a dense aggregation of small satellites, densest where brightest, widest apart where most faint. In fact it may be shewn that if a system of rings of such proportion was constructed of iron it must become semi-fluid under the

[h] *Month. Not.*, vol. xvi. p. 43. Dec. 1855.
[i] *Ibid.*, p. 30.
[k] *Ibid.*, p. 124 (March 1856).
[l] An important series, by Bessel, will be found in *Ast. Nach.*, vol xii. Nos. 274 5. Feb. 18, and March 7, 1835.

forces it would experience. Considered as a system, the rings are sensibly more luminous than the planet (a fact which Hooke pointed out as long ago as 1666), and **B** is brighter than **A**. **B** itself is perceptibly less bright at its inner edge than elsewhere. At the epoch of the Saturnian equinoxes the ansæ do not both disappear and reappear at the same time, and at these periods they are sometimes of unequal magnitude.

On Oct. 9, 1714, 6 days before the actual passage of the Earth through the plane of the ring, and whilst the ansæ were decreasing, Maraldi noticed that the Eastern one appeared a little broader than the other for 3 or 4 nights, and yet it vanished first[m]. He was

Fig. 66.

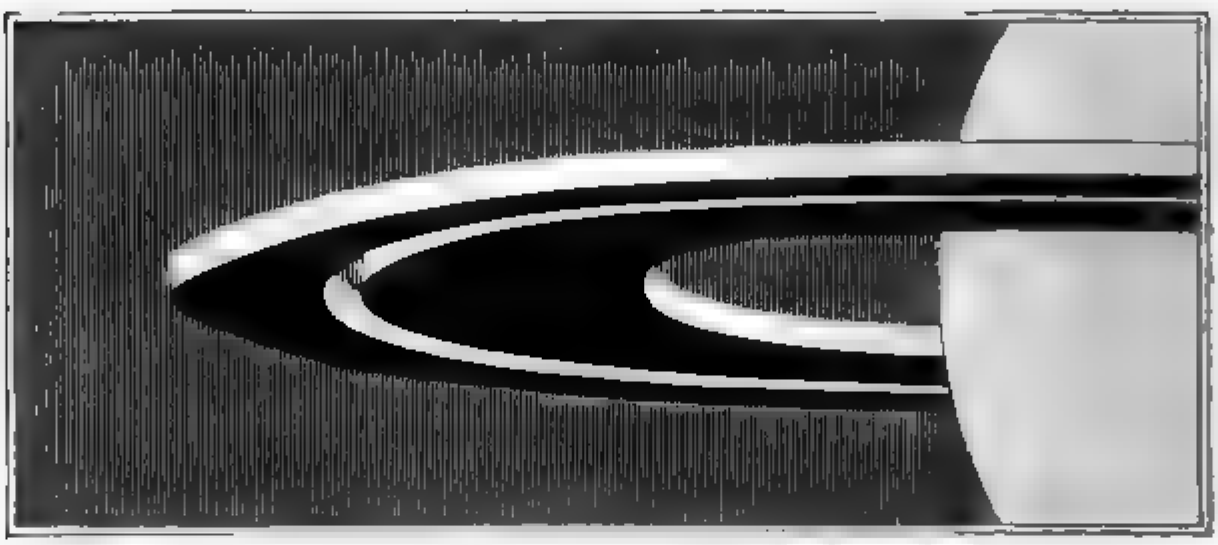


Diagram illustrating the Phenomenon of Saturn's Ring "beaded."

induced to suspect that the ansæ had changed places by rotation, and that at any rate the surface of the rings was very irregular, the 2 rings lying moreover in different planes.

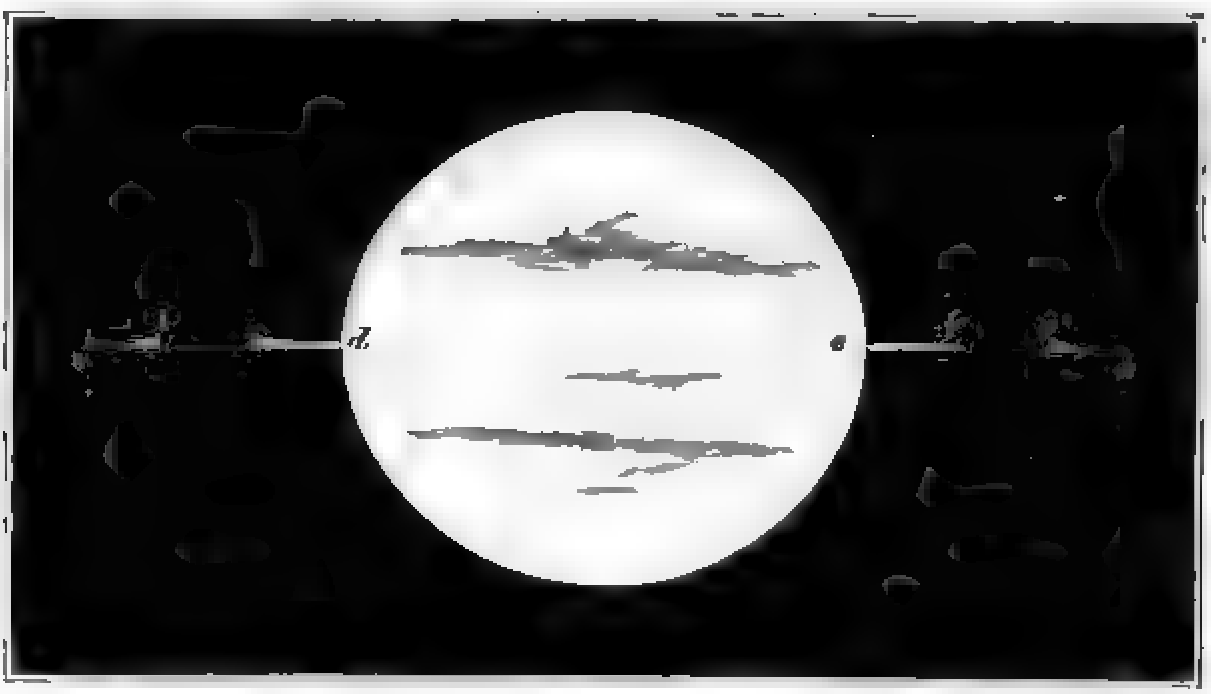
Heinsius, Varela, Messier, and many others have noticed the ansæ to be of different lengths, and that one is frequently visible without the other. When only one is visible, it is most frequently that on the Western side—a fact for which it is difficult to account.

When at its nodes the ring frequently appears broken, shewing merely luminous elongated beads seemingly detached from one another. For a long time astronomers were in doubt as to the cause of these appearances, and it was not till so recently as 1848 that the question was cleared up. In that year the observers at Harvard College, U. S., instituted a careful inquiry, and their

[m] *Mem. Acad. des Sciences*, 1715, p. 12.

micrometrical observations shewed that these "heads" were due to the concurrent effect of light reflected by the edges, external and internal, of the rings. The Figures [66–7] are copied from Bond's memoir, but ring **C** is omitted that matters may be simplified. What follows I cite from Webb, who has devoted much time to the elucidation of Saturnian facts. "It must be borne in mind that this design is an intentional exaggeration for clearness' sake, representing the dark surface much more expanded than it ever really is, and the thickness of the rings many (they say perhaps 10) times too great. To this they add the qualification that the edges should

Fig. 67.



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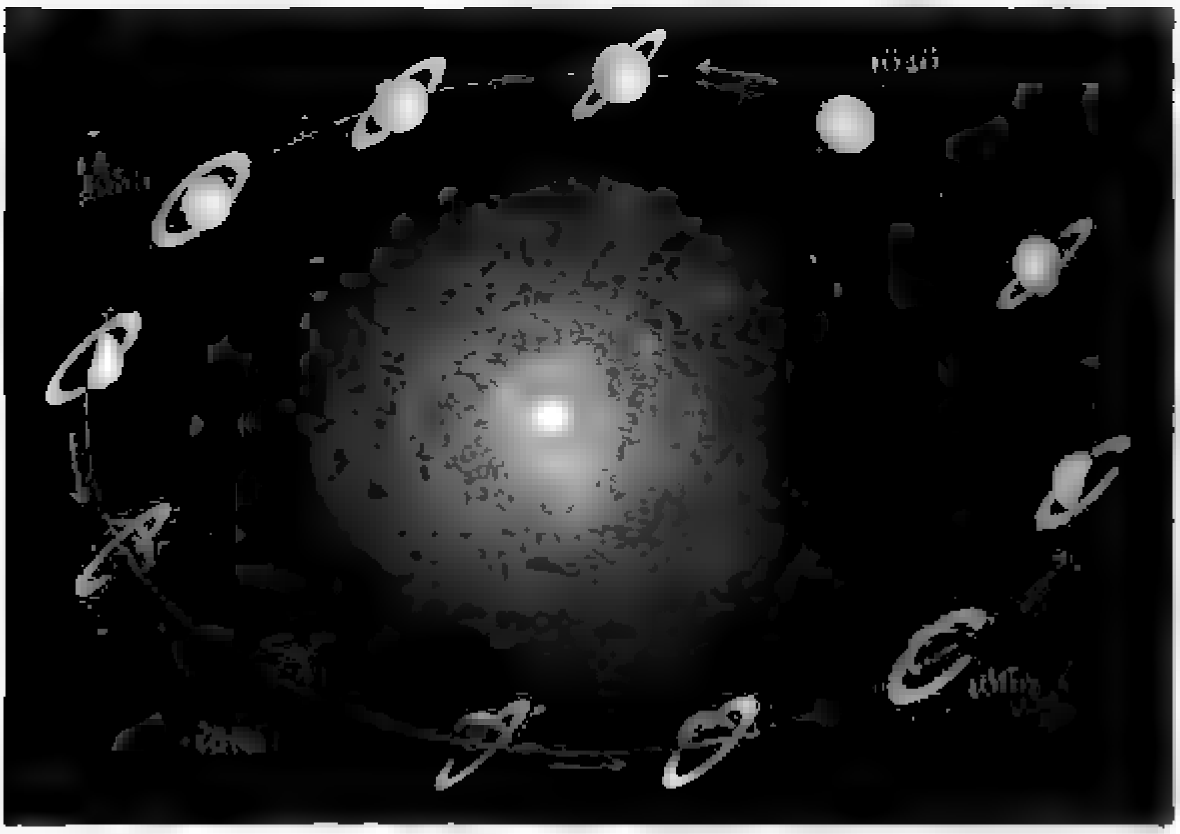
be rounded; and I should be inclined to suggest another, that **A** may probably be much thinner than **B**, so that its inner edge would add little to the effect. Comparing, then, Fig. 66 with Fig. 67, we should have,—1. A narrow dark band upon the planet, slightly curving upwards, and consisting of both the dark side of the ring and its shadow (the latter not inserted in Fig. 66). 2. The outer edge of **A** visible throughout, but with extreme difficulty when alone, as between *b* and *c*, and *f* and *g*, and towards *a* and *h*. 3. Two brighter portions from *c* to *d*, and from *e* to *f*, where the light of **A** is reinforced by that reflected by the inner edge of **B**. 4. Two bright knots where the same light, strengthened by the concurrent reflection from the inner edge of **A** and the outer of **B**

The plane of the rings is inclined 28° 10′ to the ecliptic, and intersected it in 1860 in longitude 167° 43′ 10″ and 347° 43′ 10″ (17¾° of Virgo and Pisces); the former point being the place of the ascending node, and the latter that of the descending node. According to Bessel the longitude of the node of the ring referred to the ecliptic increases at the rate of 46·462″ *per annum*.

Whether viewed from the Earth or from the Sun, the phenomena seen in connexion with the rings of Saturn are much the same, but the motion of the Earth in its orbit (the inclination of which differs

Fig. 59.

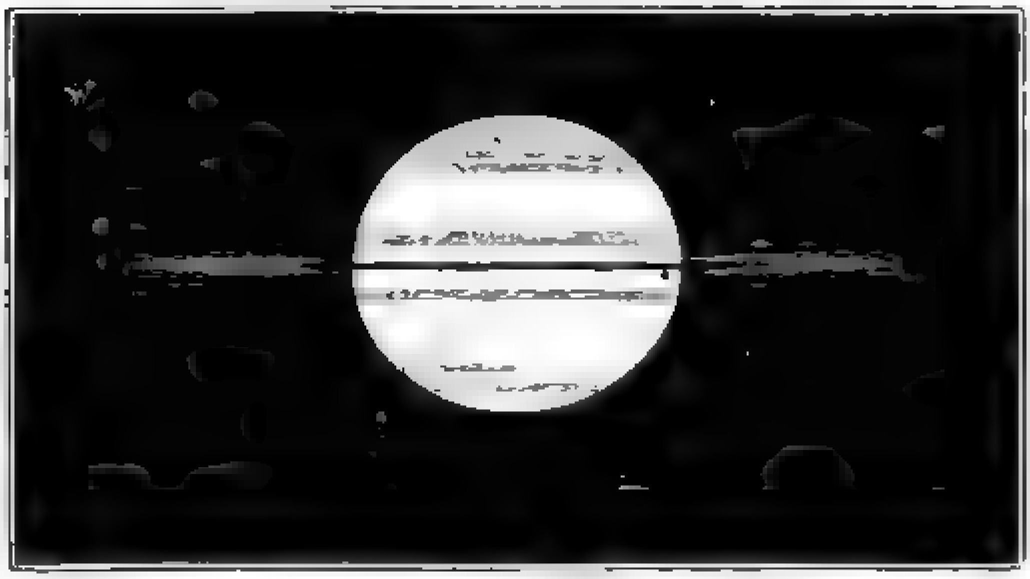


Phases of Saturn's Rings.

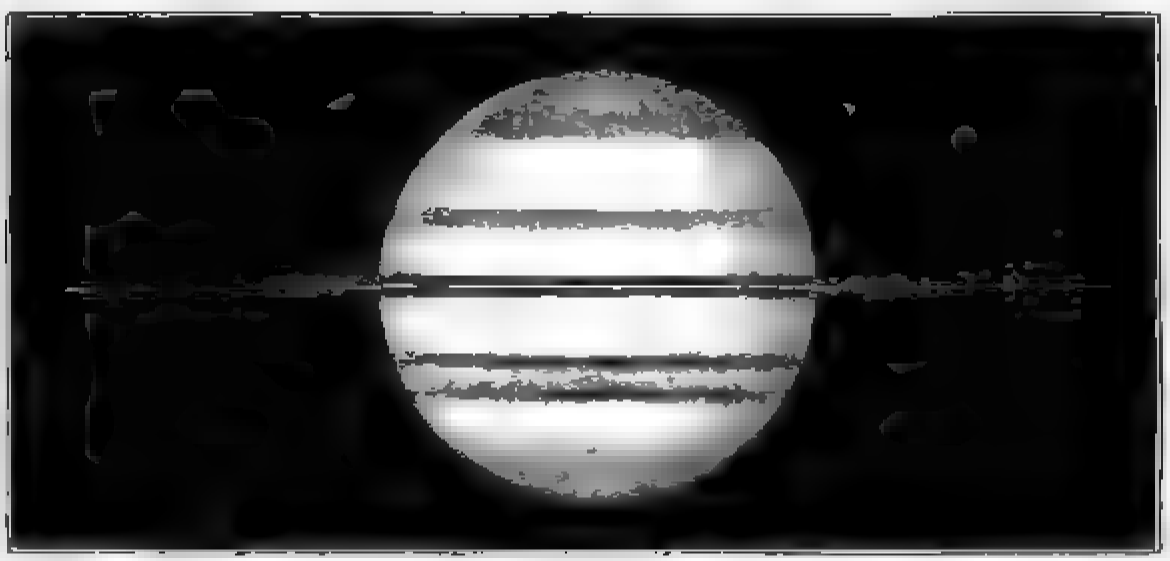
somewhat from that of Saturn) gives rise to certain phases in the rings which would not be witnessed by an observer placed on the Sun. "Thus it usually happens that there are 2, if not 3*, disappearances about the time of the planet's arrival at the nodes. The plane of the ring may not pass through the Earth and Sun at the same time, but the ring may be invisible under both conditions, because its edge only will be directed towards us. It is also invisible when the Earth and Sun are on opposite sides of

* There can really never be more than *two* disappearances.

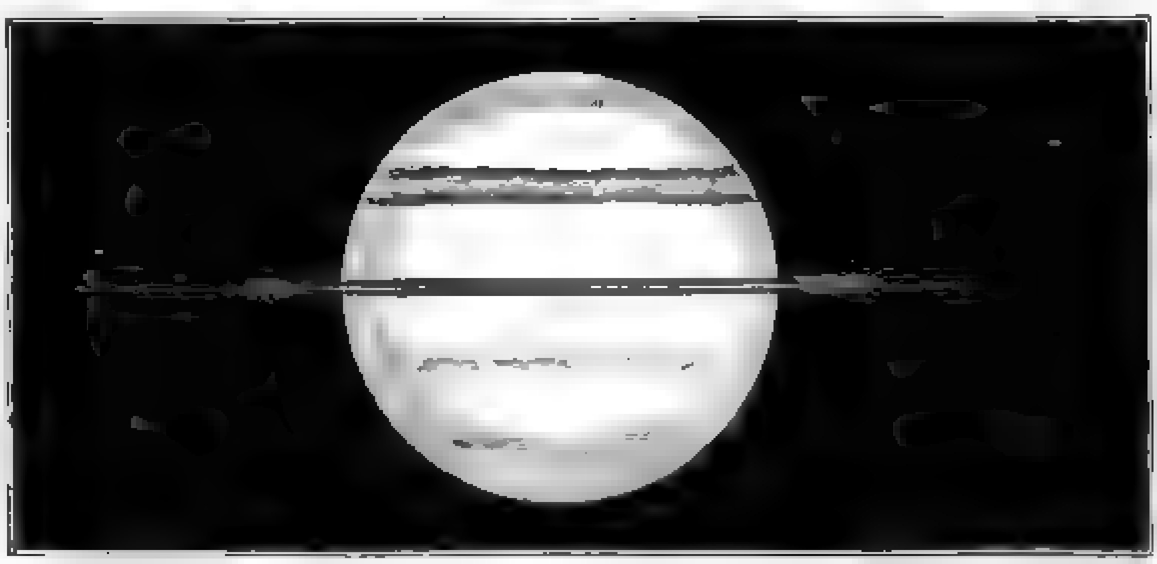
Figs. 60–2. *Plate* IX.



1861 : November. (*Anon.*)



1861 : Dec. 26. (*Wray*)



1862 : Jan. 5 (*Wray*)

SATURN.

its plane—a state of things that may continue a few weeks: in this case we have the dark surface turned towards our globe. In very powerful telescopes it has been found that the disappearance of the ring is complete under the latter condition; it has, however, been perceived as a faint broken line of a dusky colour, not only when the Sun is in its plane, but likewise when its edge is directed to the Earth. Our remarks must be considered as applying to observations with telescopes in common use." The foregoing quotation is from Hind[d]; a fuller account is given by Sir John Herschel[e], but it is beyond my purpose to go further into this subject.

Saturn's period being $29{\cdot}458^y$, the half of this, or $14{\cdot}729^y$, will be the average time elapsing between 2 nodal passages. Such a passage took place in 1862. The Southern surface of the ring had then been visible for $14{\cdot}7^y$.

In Jan. 1856 the planet was in $77{\cdot}5°$ of longitude, one of the two places at which the greatest opening of the rings occurs. From this time the breadth diminished till Nov. 23, 1861, when the motion of the planet and of the Earth again brought the ring edgewise to the Earth and caused it to disappear, the Sun being South of the plane, and the Earth crossing to the North. On Jan. 31, 1862, the Sun, passing through the plane of the ring, began to illuminate its Northern surface, and the Earth being also on that side, the ring reappeared. On May 17 the Earth went to the South, and the Sun remaining on the North, a second disappearance took place. The ring remained invisible, in consequence of presenting its unilluminated side to us, till Aug. 12, 1862, when the Earth once more passing through the plane of the ring to the North, brought the Northern side into view—a state of things which will last till 1877. The last greatest opening out of the ring occurred in Aug. 1869, the planet being in longitude $257{\cdot}5°$: the next will occur in June 1885, with the planet in longitude $77{\cdot}5°$.

It will be seen from De La Rue's drawing of 1856 [Fig. 55], and from others taken at the epoch of maximum breadth, that the ball is at such times entirely encompassed by the ring, and that thus the outline of the whole system is a perfect ellipse: this state of

[d] *Introd. to Ast.*, p. 107. [e] *Outlines of Ast.*, p. 343 *et seq.*

things always lasts for several months. The ring of Saturn is most open when the planet is in either Gemini or Sagittarius.

By a careful examination of the ring Sir W. Herschel ascertained that it revolves round the ball in $10^h\ 32^m\ 15^s$—a period not greatly in excess of that of the planet's own axial rotation: the direction is the same in both cases. There are, however, great difficulties in the way of admitting this rotation [f].

In 1854–5–6, Secchi executed numerous measures of the rings, but they exhibited considerable discordances. He afterwards found that whilst those of 2 consecutive days did not harmonise, those of 3 and 9 days did; and the idea then occurred to him that the results might be explained by supposing the ring to be elliptical, presenting sometimes its longer, sometimes its shorter diameter. He failed to reconcile Herschel's period of rotation with his own observations, but found that a period which corresponds with that which a satellite placed on the margin of the ring would have (namely, $14^h\ 23^m\ 18^s$) would satisfy them [g].

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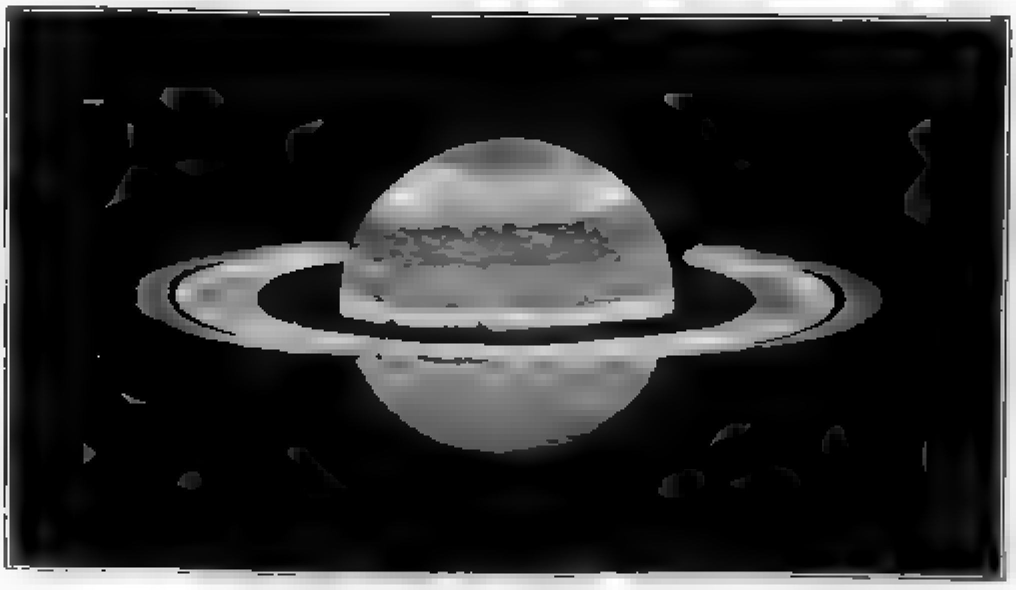
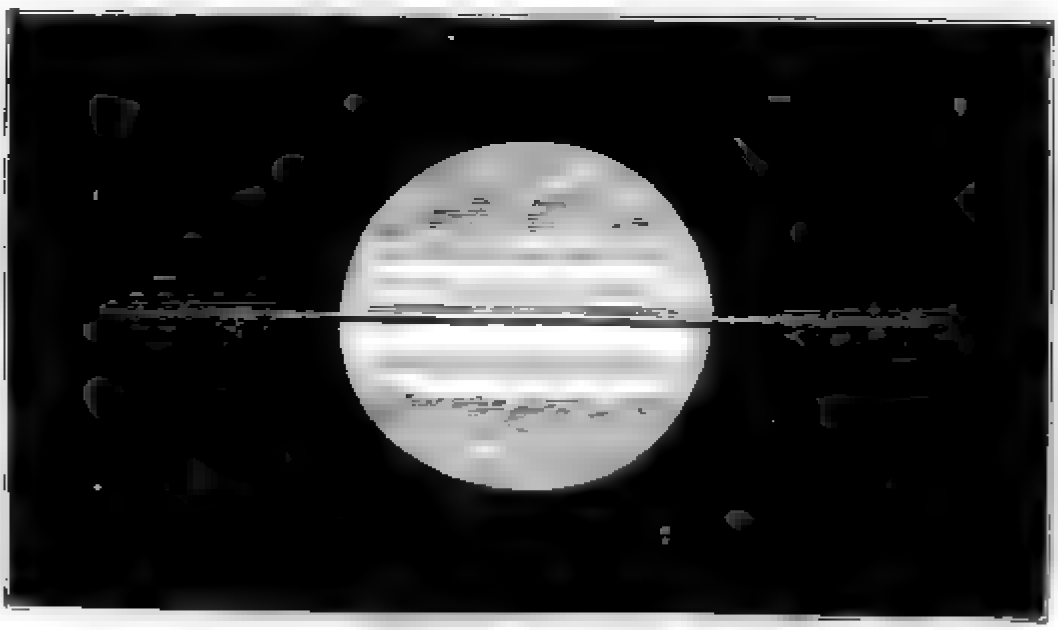


1861 April 7. (*De La Rue*)



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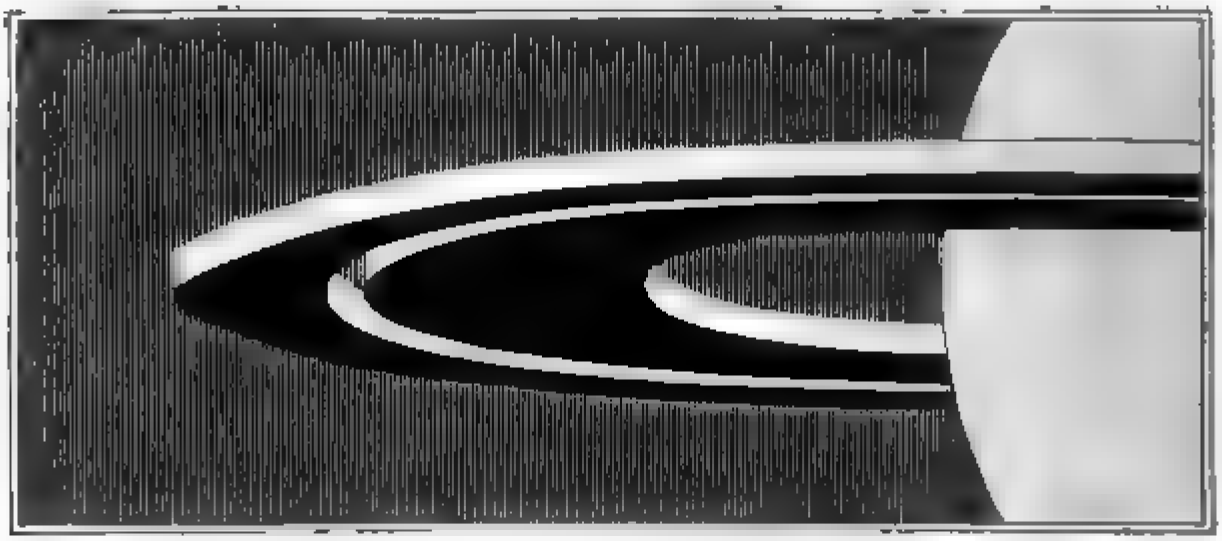

Diagram illustrating the Phenomenon of Saturn's Ring "beaded."

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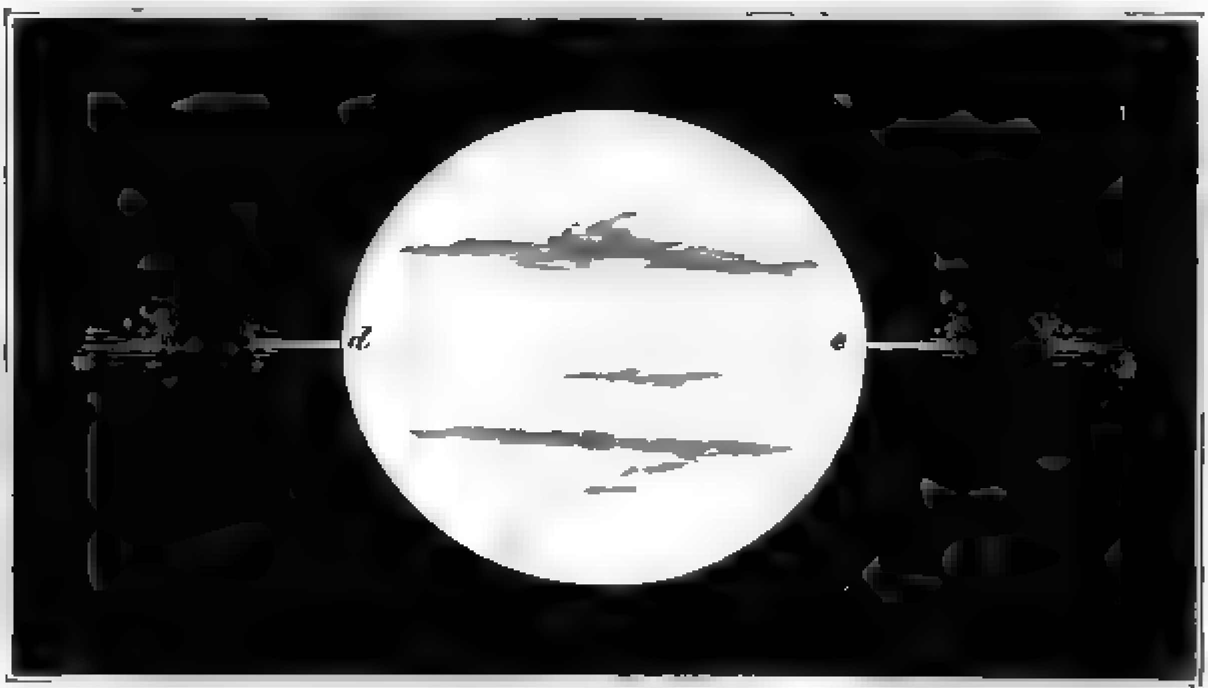

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(the latter, it may be presumed, many times outweighing the former), reaches us through the opening of Ball's division. This the Americans considered fully satisfactory, the curvature of the black stripe having been noticed, and estimated at 0·25″; the extremities of the line, and the beads, falling beneath its direction, as from the diagram they ought to do, and the accordance of measures fully bearing out the impression of Nov. 3, that the 'interruptions in the light of the ring are so plainly seen, that no one could for a moment hesitate as to their explanation.'"

O. Struve many years ago propounded a theory[n] that the rings were expanding inwards (so that ultimately they would come in contact with the ball); and also that between the time of J. D. Cassini and Sir W. Herschel the breadth of the inner ring had increased in a more rapid ratio than that of the outer ring, while the exterior diameter of **A** was unchanged. Struve drew this conclusion from the early observations of Huyghens and others: but it is doubtful if these are to be relied upon; and the Rev. R. Main has shewn, by micrometric measures obtained by himself, that the theory is untenable. Kaiser also considered it to be destitute of foundation[o]. On the other hand, both Hind[p] and Secchi[q] favour the idea of change.

The rings cast a shadow; and from observing this shadow some persons have been led to think that the surfaces of the rings are convex[r], and that they do not lie in precisely the same plane. Sir J. Herschel doubted the former being a legitimate conclusion from *observation*, but admitted its theoretical probability[s]. Lassell considers that **C** often changes colour, *each* end being alternately bluish-gray and brownish[t]. This may indicate rotation. Hippisley thinks that there is evidence that the ring **A** lies in a different plane from the others, and that **B** is thicker in the middle than at either of the edges[u]. Sir W. Herschel surmised that the ring is not flat, but that the inner edge was hemispherical or hyperbolical[x]. The outer edge of **B** is commonly the brightest portion of the system,

[n] An abstract of it appears in *Month. Not.*, vol. xiii. p. 22. Nov. 1852.

[o] See *Month. Not.*, vol. xvi. p. 66, Jan. 1856, for an abstract of Kaiser's memoir.

[p] *Month. Not*, vol. xv. p. 31. Nov. 1854.

[q] *Month. Not*, vol. xvi. p. 50. Jan. 1856.

[r] De La Rue's drawing forcibly conveys the impression of this as regards **B**.

[s] *Outlines of Ast.*, p. 343.

[t] *Month. Not.*, vol. xiii. p. 147. March 1853.

[u] *Month. Not.*, vol. xiv. p. 163 March 1854.

[x] *Phil. Trans.*, vol. xcvi. p. 463. 1806.

but Schwabe and Webb believe it to be variable; the inner edge of the same ring is usually much the dullest, but occasionally it brightens up. G. P. Bond in 1856 regarded the dark shading visible at the inner edge of **B** as a sharply-defined dark area, elliptical in form and concentric with the rings, but of greater eccentricity. Prince "is convinced" that **C** is becoming more and more illuminated[y]. Lassell and De La Rue have suspected the existence of mountains on the rings, in consequence of elevations appearing in the shadow projected on the ball[z]. [Fig. 63, Pl. X.] Jacob saw the effect, but doubted the assigned cause, preferring to think that it is an illusion arising from inequalities in the depth or tone of the shadow[a]. In 1848, when the unilluminated side was turned towards us, Dawes saw traces of the shadow, of a coppery hue, and he regarded this as an effect due to a rather dense atmosphere[b]: but more than this, the atmosphere causing a refraction of the solar light on each side of the ring would reduce the shadow of the ring to a penumbra, and thus account for it being imperceptible when the *Sun* was in the plane of the ring. Sir W. Herschel had previously believed that an atmosphere surrounding the ring alone would explain a distortion which he noticed in 1807, at the South pole, in optical proximity to the ring; the other pole being at the same time clear of the ring and free from distortion[c].

In general the brightness of the ball and of the rings is tolerably uniform, but there are exceptions to this rule. In April 1862 Lassell noted the rings to be very dull compared with the ball, but this might have been due to the small elevation of the Sun above the plane of the ring. Probably any peculiarities of this nature which may be noticed from time to time are optical effects, and do not depend on actual change.

Bessell entered upon some investigations to determine the mass of the rings, by ascertaining their perturbing effect on the orbit of the 6th satellite, Titan. He estimated it at $\frac{1}{118}$ of the mass of the planet[d]. The thickness of the rings being too minute for measurement, no precise determination of their density is attainable; if, however, we assume it as approximately equal to that of the planet,

[y] *Month. Not.*, vol. xx. p. 212. March 1860.

[z] *Ibid.*, vol. xxi. pp. 177 and 236. April and June 1861.

[a] *Ibid.*, vol. xxi. p. 237. June 1861.

[b] *Month. Not.*, vol. x. p. 46, Dec. 1849, and vol. xxii. p. 298, June 1862.

[c] *Phil. Trans.*, vol. xcviii. p. 162, 1808.

[d] *Conn. des Temps*, 1838, p. 29.

as is probably the case, it will follow that the thickness is about 138 miles—a quantity which is very nearly the mean of the 2 estimations of Sir J. Herschel and Bond. Supposing this to be correct, at the mean distance of the planet the rings would only subtend an angle of about 0·03″; it may therefore be readily inferred that the ring will at stated times become wholly invisible even in the most powerful telescopes.

Saturn is attended by 8 satellites, 7 of which move in orbits

Fig. 68.

General view of Saturn and its Satellites.

whose planes coincide nearly with that of the planet's equator, and therefore with the plane of the rings also: the orbit of the remaining and most distant satellite is inclined about 12° 14′ (Lalande) to the aforesaid plane. The consequence of this coincidence in the orbits of the first 7 satellites is that they are always visible to the inhabitants of both hemispheres when not under eclipse in their primary's shadow.

In dealing with the satellites of Saturn I continue to follow my usual plan of tabulating as much information as possible, but when we have proceeded beyond Jupiter, data concerning satellites become both scarce and contradictory, and it is frequently necessary to give alternative statements.

THE SATELLITES OF SATURN.

Names.	Order of Discovery.	Discoverer.		Mean Distance.			Sidereal Period.		E. of orbit.	Diameter.		Diam. seen from ♄	App. Diam. of ♄ seen from Satel.	App. Star Mag.
				Apparent.	Rad. of ♄	Miles.				⊕ = 1.	Miles.			
				′ ″			d. h. m.	d.				′	°	
1. Mimas ..	7	Sir W. Herschel.	1789, Sept. 17	0 26·78	3·360	120,800	0 22 37	0·94	0·069	0·12	1000		16·5	17
2. Enceladus	6	,,	1789, Aug. 28	0 34·38	4·312	155,000	1 8 53	1·37	Uncertain.	..	?		13·0	15
3. Tethys ..	5	J. D. Cassini.	1684, March	0 42·57	5·339	191,900	1 21 18	1·88	0·005	0·07	500		10·6	13
4. Dione ...	4	,,	1684, March	0 54·54	6·839	245,800	2 17 41	2 73	0·020	0·07	500		8·3	12
5. Rhea	3	,,	1672, Dec. 23	1 16·16	9·552	343,400	4 12 25	4·51	0·023	0·17	1200		6·0	10
6. Titan	1	C. Huyghens.	1655, March 25	2 56·55	22·145	796,100	15 22 41	15·94	0·029	0·42	3300	25·0	2·6	8
7. Hyperion	8	{W. Bond and Lassell.}	1848, Sept. 19	3 33·3	26·783	963,300	21 7 7	21·29	0·115	..	?		2·1	17
8. Iapetus ..	2	J. D. Cassini.	1671, Oct. 25	8 34·52	64·359	2,313,800	79 7 53	79·33	0·025	0·26	1800		0·9	9

It is understood that Dawes claimed to share with Lassell the English discovery of Hyperion, those observers being in company, on the said 19th of September, 1848.

The figures in the column of "Diameter" are, with the exception of Titan's, extremely doubtful.

Mimas. Beer and Mädler's reduction of Sir W. Herschel's observations in 1789 gives for the epoch of Sept. 14^d 13^h 26^m Slough M. T., the Saturnicentric λ at 264° $16'$ $36''$, the longitude of the peri-saturnium at $104{\cdot}42^\circ$, and the eccentricity at 0·068.

Enceladus. Beer and Mädler, also from Sir W. Herschel's observations, give for the epoch of 1789, Sept. 14^d 11^h 53^m, the λ at 67° $56'$ $26''$: they consider the orbit to be circular in the plane of the ring. Hind says that Enceladus was *seen* by Sir W. Herschel on Aug. 19, 1787.

Tethys. Lamont, from his own observations in 1836, found for the epoch of April 23^d 8^h 27^m Greenwich M. T., the λ to be 158° $31'$, the longitude of the peri-saturnium 357° $37'$, the ☊ 184° $36'$, the eccentricity 0·0051, and the inclination of the orbit to the plane of the ring 1° $33'$. Sir John Herschel, about the same time, found the λ to be 313° $43'$, the longitude of the peri-saturnium to be 53° $40'$, the eccentricity 0·04217, and the orbit to be precisely in the plane of the ring. The serious differences in these two results are to be ascribed to errors in the observations arising from the difficulty attending them, but such differences naturally make us distrust the entire batch of figures.

Dione. Sir John Herschel in 1836 found the λ to be 327° $40'$, the longitude of the peri-saturnium 42° $30'$, the eccentricity 0·0206, and the orbit to be precisely in the plane of the ring.

Rhea. Sir John Herschel in 1835–7 found the λ to be 353° $44'$, the longitude of the peri-saturnium 95°, and the eccentricity 0·02269. The inclination is very small.

Titan[*], as the satellite most easily seen, has naturally received most attention. Bessel's determination of its orbit is reputed to be the most complete. For the epoch of 1830·0 he gave the λ at

* When Huyghens discovered this satellite in 1655, he was imprudent enough to predict that there were no others, because Titan being the 6th secondary planet, and there being only 6 primary planets known, Nature's (supposed) laws of symmetry were satisfied. The danger of prediction in matters of this kind is well illustrated in the case of Mr. John Harris, F.R.S. That learned gentleman published a book in 1729, in which he says: "'Tis highly probable that there may be more than 5 moons revolving round this remote planet [the number of satellites which Saturn was then known to possess]; but their distance is so great as that they have hitherto escaped our eyes, and perhaps may continue to do so for ever; *for I do not think that our telescopes will be much further improved!!*"

137° 21′, the longitude of the perisaturnium at 256° 38′, and the eccentricity 0·029314. The line of apsides has a direct motion of 30′ 28″ on the ecliptic, completing a revolution in 718 years, the nodes completing a revolution in 3600 years.

Hyperion has been so recently discovered that its orbit has not been investigated. This satellite was seen by Bond on Sept. 16, 1847, and by Lassell on Sept. 18, but it was not till the date given in the table that its character was determined.

Iapetus. Lalande for the epoch of 1790 gave the λ at 269° 37′, and the ☊ at 150° 27′, reckoned *on the orbit.*

The following elements are by Captain Jacob[f]:—

	1857. Jan. 0. λ	π	☊	ι To Eclip.	ϵ	Semi-axis maj. a	Daily Sat'centric Mot. μ
	° ′	° ′	° ′	° ′		″	°
Mimas....	210 ±	?	?	?	?	?	381·947
Enceladus	301 55	?	?	?	?	?	262·732
Tethys....	281 42	109 7	167 37	28 10	0·01086	42·60	190·697
Dione	115 30	145 4	167 37	28 10	0·00310	54·85	131·534
Rhea	288 43	185 0	167 19	28 8	0·00080	76·13	79·690
Titan	299 42	257 6	167 58	27 36	0·027937	176·90	22·577
Hyperion..	?	?	?	?	?	?	?
Iapetus ..	78 9	349 20	143 1	18 37	0·028443	514·96	4·538

It will be readily understood that the small apparent size of most of these satellites, and the consequently limited number of telescopes and observers which can be brought to bear on them, materially retards the attainment of any more perfect acquaintance with their motions, though it is reasonable to hope that the multiplication of large instruments and experienced workers now taking place will ere long lead to useful results.

Sir J. Herschel pointed out the curious circumstance that the period of Mimas is $\frac{1}{2}$ that of Tethys, and the period of Enceladus $\frac{1}{2}$ that of Dione[g]. D'Arrest further called attention to the commensurability within $\frac{1}{10}$ of a day, or $2\frac{2}{5}^{h}$, of 274 revolutions of Mimas, 170 of Enceladus, and 85 of Dione[h].

[f] *Month. Not.*, vol. xviii. p. 1. Nov. 1857.
[g] *Month. Not.*, vol. vii. p. 24. Dec. 1845.
[h] *Ast. Nach.*, vol. lvii. No. 1364. June 14, 1862.

The last disappearance of the ring, in 1862, was taken advantage of by various observers for watching the rare phenomenon of a transit of the shadow of Titan across the planet. The satellite itself was not seen on any occasion, but Dawes and others obtained several good views of the shadow[1]. The only previous observation of this kind appears to have been made by Sir W. Herschel on Nov. 2, 1789. Dawes on May 25, 1862, saw an eclipse of this satellite in the shadow of Saturn—the only instance on record.

It must not be supposed that Titan is the only satellite of which an eclipse, transit, or occultation is possible, for all the satellites are occasionally subject to these effects. This is especially true of the two innermost ones, but the small apparent size both of those and of the others offers a serious bar to their systematic scrutiny.

Celestial phenomena on Saturn must possess extreme grandeur and magnificence, the rings forming a remarkable series of arches stretched across the Saturnian heavens. The nearest satellite, Mimas, traverses its orbit at the rate of 16′ of arc in a minute of time, so that, as viewed from Saturn, it moves in 2 minutes over a space equal to the apparent diameter of the Moon. Considering the remoteness of Saturn from the Sun its satellites play a somewhat important part in the Saturnian sky as reflectors of sun-light. Nevertheless the space occupied by all of them, taken together, is believed to be only about 6 times that covered by the Moon.

The only physical fact which has been discovered in relation to the satellites of Saturn concerns Iapetus. Cassini lost that satellite soon after its discovery, but a larger telescope enabled him to find it again, and moreover to ascertain that it was subject to considerable variations of brilliancy. Sir W. Herschel, with a view of establishing this fact beyond doubt, paid much attention to Iapetus. He was able to confirm Cassini's opinion, and decided that it actually did experience a considerable loss of light when traversing the Eastern half of its orbit. He found that 7° past opposition was the place of minimum light. The conclusions deducible from this are (as Cassini himself pointed out), that the satellite rotates once on its axis in the same time that it performs one revolution round its primary; and that there are portions of its surface which are almost entirely incapable of reflecting the rays of the Sun.

[1] *Month. Not.* vol. xxii. pp 264, 297, &c. May and June 1862.

The mass of Saturn has been given at $\frac{1}{3021}$ by Newton; at $\frac{1}{3359}$ by Laplace; at $\frac{1}{3512}$ by Bouvard; and at $\frac{1}{3501.6}$ by Bessel. Jacob thought from his own observations that the mass of the whole Saturnian system did not differ much from $\frac{1}{3475}$.

"The most ancient observation of Saturn which has descended to us was made by the Chaldæans, probably at Babylon, in the year 519 of Nabonassar's period, on the 14th of the month *Tybi*, in the evening; when the planet was observed to be 2 digits below the star in the southern wing of Virgo, known to us as γ Virginis. The date given by Ptolemy, who reports this observation in his *Almagest* [lib. xi.], answers to B.C. 228, March 1[k]."

An occultation of this planet by the Moon is recorded to have been observed by one Thius, at Athens, on Feb. 21, 503 A.D.

Cassini observed in 1692 the occultation of a star by Saturn's satellite Titan. No other instance of this kind is on record.

From Saturn the Sun only appears about 3′ in diameter, and the greatest elongations of the planets are: Mercury, 2° 19′; Venus, 4° 21′; Earth, 6° 1′; Mars, 9° 11′; Jupiter, 33° 3′—so that a Saturnian, assuming his visual powers to resemble ours, can only see Jupiter, Uranus, and Neptune with the naked eye, and Mars perhaps by some optical aid. Saturn, on account of its slow dreary pace, was chosen by the alchemists as the symbol for lead.

In computing the places of Saturn, the Tables of A. Bouvard, published in 1821, have long been used, but new Tables by Le Verrier will soon supersede them. Tables of the satellites have still to be formed, and are a great desideratum.

[k] Hind, *Sol. Syst.*, p. 117.

CHAPTER XIII.

URANUS. ♅

Circumstances connected with its discovery by Sir W. Herschel.—Names proposed for it—Early observations.—Period, &c.—Physical appearance.—Position of its axis—Attended by 4 Satellites.—Table of them.—Miscellaneous information concerning them.—Mass of Uranus.

ON March 13, 1781, whilst engaged in examining some small stars in the vicinity of H. Geminorum, Sir W. Herschel noticed one which specially attracted his attention: and desirous of knowing more about it, he applied to his telescope higher magnifying powers, which (in contrast to their effect on fixed stars) he found increased the apparent diameter of the object under view considerably; this circumstance clearly proving its non-stellar character. Careful observations of position shewing it to be in motion at the rate of 2½″ per hour, Herschel conjectured it to be a comet, and made an announcement to that effect to the Royal Society on April 26[a]. Four days after its first discovery it was observed by Maskelyne, then Astronomer Royal, who seems to have suspected at the time its planetary character, and in the course of the following 2 or 3 months it received the attention of all the leading observers of Europe. So soon as sufficient observations were accumulated, attempts were made by various calculators to assign parabolic elements for the orbit of the new body; though but little success attended their efforts. It was found that although a parabola might be obtained which would represent with tolerable accuracy a limited number of observations, yet a larger range always revealed discrepancies which defied all endeavours to reconcile them with positions assigned on any parabolic hypothesis.

[a] *Phil. Trans*, vol. lxxi. p. 492. 1781.

The final determination was only arrived at step by step, and to Lexell must be ascribed the credit of first announcing, with any amount of authority, that the stranger revolved round the Sun in a nearly circular orbit, and that it was a planet and not a comet; though priority for this honour has been contested on behalf of Laplace.

The question of a name for the new planet was the next subject of debate. Herschel himself, in compliment to his sovereign and patron King George III, proposed that it should be called the *Georgium Sidus*; Laplace suggested the personal name of *Herschel*; but neither of these gave satisfaction to the Continental astronomers, who all declared for a mythological name of some kind. Prosperin considered *Neptune* appropriate, on the ground that Saturn would then be found between his two sons Jupiter and Neptune. Lichtenberg advanced the claims of *Astræa*, the goddess of justice, who fled to the confines of the system. Poinsinet thought that as Saturn and Jupiter, the fathers of the gods, were commemorated astronomically, it would be unpolite longer to exclude the mother, *Cybele*. Ultimately, however, as is well known, Bode's *Uranus* was placed at the top of the poll. A symbol was manufactured out of the initial of Herschel's surname, though in Germany, at the instigation of Köhler, one not differing much from that of Mars was adopted.

It soon became a matter of inquiry whether the new planet had ever been seen before, and here may be brought in a note of Arago's:—"If Herschel had directed his telescope to the constellation Gemini 11 days earlier (that is, on March 2 instead of March 13), the proper motion of Uranus would have escaped his observation, for on the 2nd the planet was in one of its stationary points. It will be seen by this remark on what may depend the greatest discoveries in astronomy." A careful inspection of the labours of former astronomers shewed that Uranus had been observed and recorded as a fixed star on 20 previous occasions: namely, by Flamsteed[b] in 1690, on Dec. 13; in 1712, on March 22; in 1715, on Feb. 21, 22, 27, and April 18 (all o. s.); by Bradley in 1748, on Oct. 21; in 1750, on Sept. 13, and in

[b] Le Verrier, in his investigation of the theory of Uranus, rejected Flamsteed's observation of Feb. 22, 1715, and adopted another dated April 18, 1715. (Grant, *Hist. Phys. Ast.*, p. 165.)

1753, on Dec. 3; by Mayer in 1756, on Sept. 25; and by Le Monnier no less than 12 times—in 1750, on Oct. 14 and Dec. 3; in 1764, on Jan. 15; in 1768, on Dec. 27 and 30; in 1769, on Jan. 15, 16, 20, 21, 22 and 23; and in 1771, on Dec. 18. Had Le Monnier been a man of *order* and method it can scarcely be doubted that he would have anticipated Sir W. Herschel. Arago recollected to have been shewn by Bouvard one of Le Monnier's observations of the planet written on a paper bag, which originally contained hair-powder purchased at a perfumer's!

It will readily be understood that these early observations have been of great service to computers, inasmuch as they have been enabled to determine the elements of the planet's orbit with greater accuracy than they could otherwise have done simply by the aid of modern observations.

Uranus revolves round the Sun in 30,686·7 days, or rather more than 84 of our years, at a mean distance of 1,753,851,000 miles. The eccentricity of its orbit, which amounts to 0·04667 (rather less than that of Jupiter), may cause this to extend to 1,835,700,000 miles, or to fall to 1,672,001,000 miles. The apparent diameter of Uranus varies but slightly, as seen from the Earth; and its mean value is about 3·9″. The real diameter is about 33,000 miles. No ellipticity is yet recognised by astronomers, notwithstanding that Mädler placed it at $\frac{1}{10}$. Arago has, however, pointed out that a polar compression may exist but not always be visible, because a spheroid, when viewed in the direction of its axis, will necessarily present a truly circular outline, and this seems both the proper and a sufficient way of reconciling discordances on the subject which have been noted. Buffham on Jan. 25, 1870, thought that the ellipticity was "obvious[c]."

It has been calculated that the amount of light received by Uranus from the Sun is equal to about the quantity which would be afforded by 300 full Moons. The inhabitants of Uranus can see Saturn, and perhaps Jupiter, but none of the planets included within the orbit of the latter.

The physical appearance of Uranus may be disposed of in a few words. Its disc is commonly considered to be uniformly bright,

[c] *Month. Not.*, vol. xxxiii. p. 164. Jan. 1872.

and without spots or belts. Yet both Lassell and Buffham have fancied they have seen traces of an equatorial belt and of inequalities of brilliancy on the planet's surface. The period of axial rotation is unknown, but analogy [d] leads us to suppose that it does not differ materially from that of Jupiter or Saturn. Buffham has ventured on a conjecture that some indications of spots seen by him imply a Rotation-period of 12^h. Sir W. Herschel once fancied he had seen traces of a ring or rings, but the observation was not confirmed by himself, nor has it been by others since. Uranus is just within the reach of the naked eye when in Opposition, and may be found without a telescope if the observer knows its precise place [e].

The direction of the axis of Uranus was supposed by Sir W. Herschel to be such that if prolonged it would at each end meet the planet's orbit. In consequence of this "the Sun turns in a spiral form round the whole planet, so that even the two poles sometimes have that luminary in their zenith [f]." Buffham very roughly makes the inclination of the axis 10°.

Uranus is attended by at least 4 satellites, 2 of which were discovered by Sir W. Herschel, and 2 by recent observers [g]. Such is their extreme minuteness that only the very largest telescopes will shew them, and for this reason our knowledge of them is very limited. Their chief peculiarity is the inclination of their orbits, which for *direct motion* amounts to 101°; in other words, their Urani-centric motion is retrograde, the planes of the orbits lying nearly perpendicular ($180° - 101° = 79°$) to the planet's ecliptic. The satellites, as Sir W. Herschel remarks, describe the Northern halves of their orbits, included between the ascending and descending nodes, in virtue of movements directed from E. to W.

Sir J. Herschel pointed out to astronomers a criterion by which they will be enabled to ascertain whether their instruments are sufficiently powerful and their sight sufficiently delicate to under-

[d] See above, p. 47.

[e] It is a somewhat singular fact that the Burmese mention eight plan ts: the Sun, Moon, Mercury, Venus, Mars, Jupiter Saturn, and *Rahù*, which latter is invisible. "An admirer of Oriental literature," says Buchanan, "would here discover the Georgium Sidus, and strip the illustrious Herschel of his recent honours."

[f] Sir W. Herschel, quoted in Smyth's *Cycle*, vol. i. p. 205.

[g] Sir W. Herschel thought that he had discovered 6 satellites, which with the 2 discovered by Lassell and Struve would make a total of 8; but it is now accepted that Herschel's conclusions must have been based on some misapprehension.

THE SATELLITES OF URANUS.

	Order of Discovery.	Discoverer.		Mean Distance.		Sidereal Period.		Apparent Star Magnitude.	Max. Elong.
				Radii of ♅.	Miles.				
						d. h. m.	d.		″
1. Ariel	3	Lassell.	1847, Sept. 14	7·44	122,800	2 12 28	2·52		12
2. Umbriel ..	4	O. Struve.	1847, Oct. 8	10·37	171,200	4 3 27	4·14		15
3. Titania.. ..	1	Sir W. Herschel.	1787, Jan. 11	17·01	280,800	8 16 55	8·71		33
4. Oberon.. ..	2	" "	" "	22·75	375,600	13 11 6	13·46		44

Inclination .. .. 79° ±
Eccentricity .. .. Small.
Direction of motion .. .. Retrograde.

take with any reasonable hope of success a search for these satellites. Between the stars β^1 and β^2 Capricorni, about the middle of the interval in R. A. and slightly to the N. there is a double star whose components are of mags. 16 and 17 [= 13 and 13·6 of Argelander's magnitudes], and 3″ apart. No instrument incapable of shewing these two stars is suitable for observing the satellites of Uranus. In fact Sir John remarked that in comparison with the Uranian satellites these two stars are "splendid objects [h]."

Under these circumstances I shall be pardoned if I omit the details of the observations made by Sir William Herschel [i], his son [k], Lamont [l], O. Struve, and Lassell [m], more especially as the substance of them has been reproduced by Hind [n] and Arago [o]. Suffice it then to remark that, according to Lassell, Ariel and Umbriel are of nearly equal brightness, whilst Titania and Oberon are both much brighter than the 2 innermost satellites.

Fig. 70.

Plan of the Uranian System.

It is right to state here that under date of Jan. 11, 1853, Lassell says *he is fully persuaded that either Uranus has no other satellites than these 4, or if it has, they remain yet to be discovered;* but the assumption of 8 was accepted by Arago and other influential astronomers. Lassell, writing in 1864 from Malta, on the occasion of his second visit, reiterates his former statement.

It was found by Sir W. Herschel that the satellites disappeared when within a short distance (¼′ or thereabouts) of the planet. This occurred whichever was the side of the planet on which the satellites happened to be, thus negativing the possibility of the phenomenon being due to an atmosphere on Uranus; and Sir William was led to assume that it was merely an effect of contrast

[h] Cited by Arago in *Pop. Ast.*, vol. ii. p. 628, Eng ed., and by Smyth, *Celest. Cycle*, vol. ii p. 475.

[i] *Phil. Trans.*, vol. lxxvii. p. 125, 1787; vol. lxxviii. p. 364, 1788; vol. lxxxviii. p. 47, 1798; vol. cv. p. 293, 1815.

[k] *Mem.* R.A.S., vol. viii. p. 1. 1835.

[l] *Mem.* R.A.S., vol. xi. p. 51. 1840.

[m] *Month. Not.*, vol. viii. p. 44, Jan. 1848; vol. xii. p. 152, March 1852; vol. xiii. p. 148, March 1853. *Mem.* R.A.S., vol. xxxvi. p. 34, 1867.

[n] *Sol. Syst.*, p. 121.

[o] *Pop. Ast.*, vol. ii. p. 623.

—the comparatively great lustre of the planet overpowering the feeble glimmer of the satellites.

Hind, from Lassell's observations at Malta in 1852, has deduced the following elements:—

III. TITANIA.

Radius of orbit at the mean distance of ♅ ..	33·88″ = 288,000 miles.
Longitude of ascending node	165° 25′
Inclination of orbit	100° 34′

IV. OBERON.

Radius of orbit at the mean distance of ♅ ..	45·20″ = 384,000 miles.
Longitude of ascending node	165° 28′
Inclination of orbit	100° 34′

From the distance of Titania the same computer obtained $\frac{1}{20503}$ as the mass of Uranus, Oberon indicating $\frac{1}{20842}$; results fairly of accord with those of other observers, when the difficulties in obtaining data are considered. Encke's value was $\frac{1}{24905}$, Littrow's $\frac{1}{21000}$, Mädler's $\frac{1}{24516}$, Adams's $\frac{1}{21000}$, Lamont's $\frac{1}{24605}$, and Bouvard's $\frac{1}{17918}$. Bouvard's value is now very generally rejected as excessive.

In computing the places of Uranus the tables of A. Bouvard, published in 1821, were used up to quite a recent date. From what appears in the following chapter it will be evident that they were susceptible of material improvement, and they have now given place to those completed in 1872 by an American astronomer, Professor S. Newcomb, as to which it may be observed that they do not countenance the idea that there exists a trans-Neptunian planet.

CHAPTER XIV.

NEPTUNE[a]. ♆

Circumstances which led to its discovery.—Summary of the investigations of Adams and Le Verrier.—Telescopic labours of Challis and Galle.—The perturbations of Uranus by Neptune.—Period, &c.—Attended by 1 Satellite.—Elements of its orbit.—Mass of Neptune.—Observations by Lalande in 1795.

MORE than half a century ago an able French astronomer M. Alexis Bouvard, applied himself to the task of making a refined investigation of the motion of Uranus, in order to prepare tables of the planet. He had at his disposal the various observations by Flamsteed and others, made prior to the direct optical discovery of Uranus, and those made by various astronomers subsequent to that event in 1781. In working these up he found himself able to assign an ellipse harmonising with the first series, and also one harmonising with the second; but by no possibility could he obtain an orbit reconcileable with both. As the less objectionable alternative, Bouvard decided to *reject* all the early observations and to confine his attention solely to those more recent[b]. In this way he produced, in 1821, Tables of the planet,

[a] I cannot pass this chapter through the press without entering a protest against the conduct of many French writers in dealing with Neptune. Nothing is more common than to meet with a narrative of the discovery of Neptune, either *without any mention, direct or indirect, of Mr. J. C. Adams*, or with some casual remark to the following effect, 'In conclusion, we may state that an English astronomer of the name of Adams also paid much attention some years ago to the perturbations of Uranus:' with perhaps a foot-note to this effect—'Whatever our English neighbours may say to the contrary, the real glory of this discovery rests with our countryman Le Verrier.'

[b] A memorable illustration of the folly and impolicy of rejecting *any* observation, merely because it opposes—or seems to oppose—a pre-conceived theory.

fairly representing its motion in the heavens. This agreement, however, was not of long duration, and a few years only elapsed before discordances appeared of too marked a character to be possibly due to any legitimate error in the Tables: constructed in the form in which they existed it was evident that they were defective in principle. Bouvard himself, who died in 1840, seems to have fancied that an exterior planet was alone the cause of the irregularities existing in the motion of Uranus, and the Rev. T. Hussey was led to assert this in decided terms in a letter to Mr. Airy in 1834. This conviction soon forced itself on astronomers[c], and amongst others on Valz, Somerville, Mädler, and Bessel. Bessel, it would seem, entertained the intention of mathematically inquiring into the matter, but was prevented by an illness, which eventually proved fatal.

Mr. J. C. Adams, whilst a student at St. John's College, Cambridge, resolved to attack the question, and, as he found subsequently, entered a memorandum to this effect in his diary under the date of July 3, 1841, but it was not till January 1843 that he found himself with sufficient leisure to commence. He worked in retirement at the hypothesis of an exterior planet for $1\frac{3}{4}$ years, and in Oct. 1845 forwarded to Mr. Airy some provisional elements for one revolving round the Sun at such a distance and of such a mass as he thought would account for the observed perturbations of Uranus. This was virtually the solution of the problem in a theoretical point of view, and it is much to be regretted that neither the result nor any of the circumstances attending it were made public at the time.

In the summer of 1845, M. Le Verrier, of Paris, turned his attention to the anomalous movements of Uranus, and in the November of that year published his first memoir to prove that they did not depend solely on Jupiter and Saturn. In June 1846 the French astronomer published his second memoir to prove that an exterior planet was the cause of the residual disturbance. He assigned elements for it, as Adams had done 8 months previously. A copy of the memoir reached Mr. Airy on June 23, and finding how closely in accord Le Verrier's hypothetical elements were with

[c] As far back as October 25, 1800, Lalande and Burckhardt came to the conclusion that there existed an unseen planet beyond Uranus. (*Year Book of Facts*, 1852.) I know not on what grounds this statement rests.

those of Adams, which were still in his possession, he was so impressed with the value of both, that on July 9 he wrote to Professor Challis of Cambridge to suggest the immediate employment of the large "Northumberland" telescope in a search for the planet. The proposal was agreed to, and on July 11 a systematic search was commenced. Challis, not being in possession of the Berlin Star Map of the particular locality in which it was supposed that the looked-for planet would be found, was forced to make observations for the formation of a map for himself; this was done, but much valuable time was occupied, and it was not till Sept. 29 that the diligent Professor found an object whose appearance attracted his attention, and which was subsequently proved to be the new planet so anxiously sought. It was likewise ascertained afterwards that the planet had been observed for a star on Aug. 4 and 12, and that the supposed star of Aug. 12 was wanting in the zone of July 30. The non-discovery of its planetary nature on Aug. 12 was due to the fact of the comparisons not having been carried out quite soon enough; a pardonable though regrettable circumstance.

In August Le Verrier published a third memoir, containing revised elements, in which particular attention was paid to the probable position of the planet in the heavens. On Sept. 23 a letter from him, containing a summary of the principal points of this memoir, was received by Encke of Berlin, whose co-operation in searching telescopically for the planet was requested. The Berlin observers had the good fortune to have just become possessed of Bremiker's Berlin Star Map for Hour XXI. of R. A., which embraces that part of the heavens in which both Adams and Le Verrier expected that the new planet would be found. On turning the telescope towards the assumed place, Galle, Encke's assistant, saw what seemed to be a star of the 8th magnitude, which was not laid down on the map. Further observations on Sept. 24 placed it beyond a doubt that this 8th-magnitude star was in reality the trans-Uranian planet; a discovery, the announcement of which, as may be well imagined, created the liveliest sensation. The French astronomers, with Arago at their head, disputed with unseemly violence the equal claims of Adams to participate with Le Verrier in the honours, but Mr. Airy, the Astronomer Royal, laid before the Royal Astronomical Society, on Nov. 13, such an

overwhelming chain of evidence in favour of our distinguished countryman's exertions as seems to all impartial minds to have finally settled the question [d].

The intellectual grandeur of this discovery will be best appreciated, so far as a non-mathematical reader is concerned, by placing in juxta-position the observed longitude of the new planet when telescopically discovered, and the computed longitudes of Adams and Le Verrier.

HELIOCENTRIC POSITIONS.

Observed by Galle	326° 52′
Computed by Adams	329° 19′
Computed by Le Verrier	326° 0′;

Adams Δ C − O = + 2° 27′
Le Verrier Δ C − O = − 0° 52′.

From this it will be seen that Le Verrier's computation proved to be slightly the more accurate of the two, a fact which in no respect militates against the equality of the merits of the two great mathematicians.

After considerable discussion *Neptune* was the name agreed upon for the new planet; Galle's suggestion of *Janus* being rejected as too significant.

"Such," in the words of Hind, "is a brief history of this most brilliant discovery, the grandest of which astronomy can boast, and one that is destined to a perpetual record in the annals of science—an astonishing proof of the power of the human intellect."

The accompanying diagram shews the paths of Uranus and Neptune from 1781 to 1840, and will illustrate the direction of the perturbing action of the latter planet on the former.

From 1781 to 1822 it will be evident, from the direction of the arrows, that Neptune tended to draw Uranus in advance of its place as computed independently of exterior perturbation.

In 1822 the two planets were in heliocentric conjunction, and

[d] The foregoing is a very bare outline of the case, which is a most interesting one. Grant (*Hist. Phys. Ast.*, p. 165 *et seq.*) gives full particulars; and reference may also be made to *Month. Not.*, vol. vii. p. 121, Nov. 1846; *Mem.* R.A.S., vol. xvi. p. 385, 1847; *Athenæum*, Oct. 3, 1846; Adm. Smyth's *Speculum Hartwellianum*, p. 405, and Sir J. Herschel's *Outlines of Ast.*, p. 533. The French case will be found stated in Arago's *Pop. Ast.*, vol. ii. p. 632; the English translator's notes to the passage are very appropriate.

the only effect of Neptune's influence was to draw Uranus farther from the Sun, without altering its longitude.

Fig. 71.

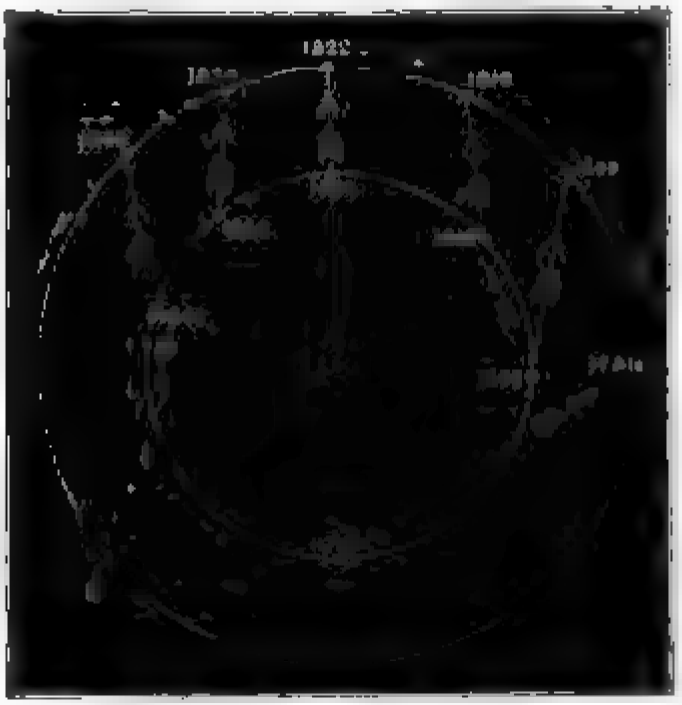


Illustration of the Perturbation of Uranus by Neptune.

From 1822 to 1830 the effect of Neptune was to destroy the excess of longitude accumulated from 1781, and after 1830 the error in longitude changed its sign, and for some years subsequently Uranus was *retarded* by Neptune; having by 1846 fallen 128″ behind its place as predicted from Bouvard's tables.

Neptune revolves round the Sun in 60,126 days, or 164·6 years, at a mean distance of 2,746,271,000 miles, which an eccentricity of 0·0087 will increase to 2,770,217,000 miles, or diminish to 2,722,325 000 miles. The apparent diameter of Neptune only varies between 2·6″ and 2·8″. Its true diameter is about 36,600 miles—a diameter somewhat greater than that of Uranus. No compression is perceptible.

Neptune is destitute of visible spots and belts, and the period of its axial rotation is unknown, and likely to remain so. Lassell, Challis, and Bond have at various times suspected the existence of a ring but nothing certain is known on the subject. It would be very desirable to have a large reflector like Lord Rosse's or a large refractor like Mr. Newall's devoted to a series of observations of this planet and Uranus, for it is nearly certain that no other existing instruments will add much to our present extremely limited knowledge of the physical appearance of these planets.

Neptune is known to be attended by one satellite, discovered by Lassell in 1846, and both that observer and the late W. C. Bond subsequently imagined that they had obtained traces of the existence of a second; though this assumption awaits confirmation.

The following table furnishes all the information we at present possess about Lassell's confirmed satellite :—

THE SATELLITE OF NEPTUNE.

	Discoverer	Mean Distance. Radii of ♆ = 1.	Mean Distance. Miles.	Sidereal Period. d. h. m.	Sidereal Period. d.	Apparent Star magnitude.	Max. Elong. ″
1	Lassell. 1846, Oct. 10	12·00	220,000	5 21 8	5·87	14	18

Hind gives the following elements*:—

Epoch 1852, Nov. 0, G. M. T.

Mean anomaly	243° 32′
Peri-neptunium	177 30
☊	175 40
ι	151 0
Eccentricity	6 5 = 0·1059748
Period	5·87694^d.

The elements are calculated for *direct* motion; accordingly it will be noticed that the actual Neptuni-centric motion of the satellite is *retrograde*—a circumstance which, except in the case of the Uranian sattellies, is without parallel in the solar system as regards planets; though there are many *retrograde* comets.

Fig. 72.

PLAN OF THE ORBIT OF NEPTUNE'S SATELLITE.

The mass of Neptune has been variously estimated at $\frac{1}{14494}$ by O. Struve; at $\frac{1}{18780}$ by Peirce; at $\frac{1}{19400}$ by Bond; at $\frac{1}{17900}$ by Hind, from a combination of early measures; at $\frac{1}{17135}$ by the same from Lassell's Malta measures; at $\frac{1}{19000}$ by Littrow; at $\frac{1}{14433}$ by Mädler; and at $\frac{1}{20039}$ by Safford, which is the most recent evaluation.

The only known observations of Neptune made previously to its discovery in 1846 are two by Lalande, dated May 8 and 10, 1795, and one by Lamont of Oct. 25, 1845. Two by the same astronomer on Sept. 7 and 11, 1846, were probably due to Le Verrier's announcement made just before, and therefore are not entitled to be regarded as casual ones.

Owing to its immense distance from the Sun, only Saturn and

* *Month. Not.*, vol. xv. p. 47, Dec. 1854. For some of Lassell's observations see vol. xii. p. 155, March 1852, and vol. xiii. p. 37, Dec. 1852.

Uranus can be seen from Neptune. Though deprived of a view of the principal members of the solar system, the Neptunian astronomers, if there be any, are well circumstanced for making observations on stellar parallax; seeing that they are in possession of a base-line of 5,590,000,000 miles, or one more than 30 times the length of that to which we are restricted.

Our present knowledge of the movements of Neptune is derived from the investigations of the late S. C. Walker, of Philadelphia, U. S., and from the Tables of M. Kowalski and Professor S. Newcomb.

BOOK II.

ECLIPSES AND ASSOCIATED PHENOMENA.

CHAPTER I.

GENERAL OUTLINES.

Definitions.—Position of the Moon's orbit as regards the Earth's.—Consequences resulting from their being inclined.—Retrograde motion of the nodes of the Moon's orbit.—Coincidence of 223 synodical periods with 19 synodical revolutions of the node.—Known as the "Saros."—Statement of Diogenes Laërtius.—Illustration of the use of the Saros.—Number of Eclipses which can occur.—Solar Eclipses more frequent than Lunar ones.—Duration of Annular and Total Eclipses of the Sun.

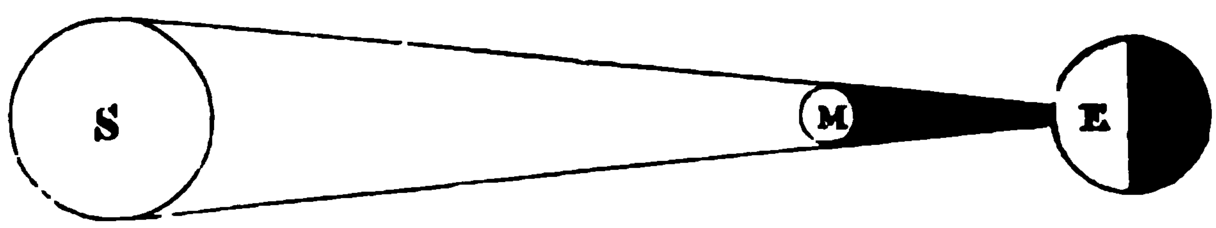
THE phenomena which I am about to describe are those resulting from the interposition of some one celestial object between the Earth and some other. We know well that inasmuch as most of the heavenly bodies are constantly in motion, the direction of lines drawn from one to another must vary from time to time; and it must occasionally happen that three will come into a right line. "When one of the extremes of the series of 3 bodies which thus assume a common direction is the Sun, the intermediate body deprives the other extreme body, either wholly or partially, of the illumination which it habitually receives. When one of the extremes is the Earth, the intermediate body intercepts, wholly or partially, the other extreme body from the view of observers situate at places on the Earth which are in the common line of direction, and the intermediate body is seen to pass over the other

extreme body, as it enters upon or leaves the common line of direction. The phenomena resulting from such contingencies of position and direction are variously denominated *Eclipses, Transits,* and *Occultations,* according to the relative apparent magnitudes of the interposing and obscured bodies, and according to the circumstances which attend them."

We will proceed to consider these several phenomena in detail, beginning with Eclipses.

It must be premised that the Moon's orbit does not lie in exactly the same plane as the Earth's, but is inclined thereto at

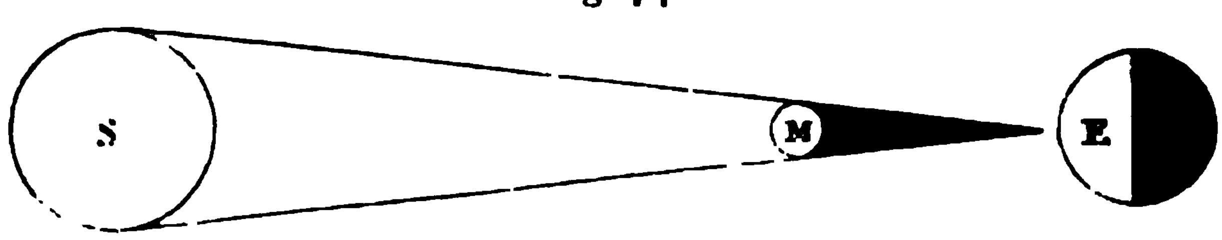
Fig. 73.



Theory of a Total Eclipse of the Sun

an angle which varies between 5° 20′ 6″ and 4° 57′ 22″, and for which 5° 8′ 45″ may be taken as the mean value. The two points where its path intersects the ecliptic are called the *nodes*, and the imaginary line joining these points is termed the *line of nodes*.

Fig. 74.



Theory of an annular Eclipse of the Sun.

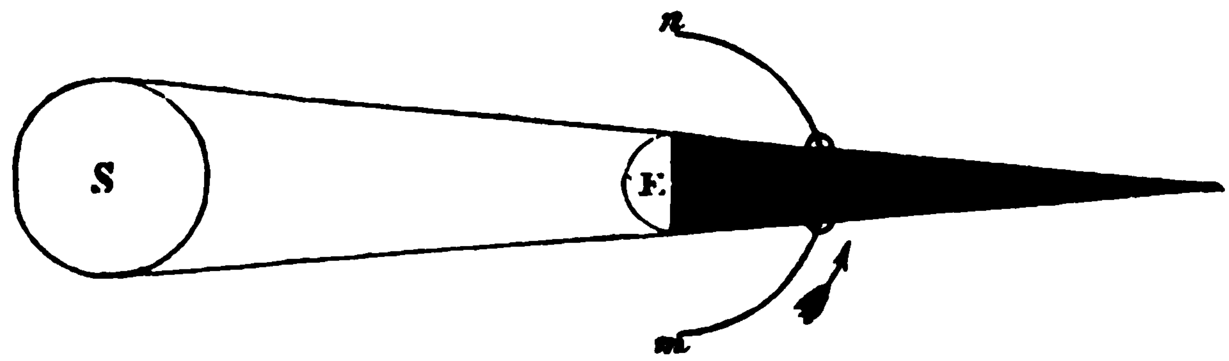
When the Moon is crossing the ecliptic from South to North, it is passing its *ascending node* (☊), the opposite point of its orbit being its *descending node* (☋). If the Moon should happen to pass through either node at or near the time of conjunction, or New Moon, it will necessarily come between the Earth and the Sun, and the 3 bodies will be in the same straight line; it will therefore follow that to certain parts of the Earth the Sun's disc will be obscured, wholly or partially as the case may be: this is an *Eclipse of the Sun.* In the figures above, S represents the Sun, E the Earth, and M the Moon. In a total eclipse the Moon's shadow reaches to and beyond the Earth, the Moon being more or less in a perigean position. In an annular eclipse the Moon's

shadow falls short of the Earth, the Moon being more or less in an apogean position.

The Earth and the Moon, being opaque bodies, must cast shadows into space; though of course, owing to the larger size of the Earth, its shadow is much the larger of the two. If the Moon should happen to pass through either node at or near the time of opposition, or Full Moon, it will be again, as before, in the same straight line with the Earth and the Sun; but the Moon will be involved in the shadow of the Earth, and therefore will be deprived of the Sun's light: this is an *Eclipse of the Moon.*

In Fig. 75, S represents the Sun, E the Earth, and *m n* the orbit of the Moon: that the Moon becomes involved in the Earth's shadow in passing from *m* to *n* is obvious.

Fig. 75.



THEORY OF AN ECLIPSE OF THE MOON.

If the orbits of the Earth and the Moon were in the same plane, an eclipse would happen at every conjunction and opposition, or about 25 times a year; but as such is not the case, eclipses are of less frequent occurrence. According to the most recent investigations, in order that an eclipse of the Sun may take place, the greatest possible distance of the Sun or Moon from the *true place* of the nodes of the Moon's orbit is 18° 36′, whilst the latitude of the Moon must not exceed 1° 34′ 52″. If, however, the distance be less than 15° 19′ 30″, and the latitude less than 1° 23′ 15″, an eclipse must take place, though between these limits the occurrence of the eclipse at any station is doubtful, and depends upon the horizontal parallaxes and apparent semi-diameters of the two bodies at the moment of conjunction. In order that a lunar eclipse may take place, the remark I have just made will equally hold good, provided only that 12° 24′, 9° 23′, 63′ 45″, and 51′ 57″, be substituted for the quantities given above.

The nodes of the Moon's orbit are not stationary, but have a

daily retrograde motion of $3' 10{\cdot}64''$ or an annual one of $19° 20' 19{\cdot}7''$, so that a complete revolution round the ecliptic is accomplished in $18^y\ 218^d\ 21^h\ 22^m\ 46^s$ nearly. The Moon performs a revolution with respect to the node in $27^d\ 5^h\ 5^m\ 36^s$ ($27{\cdot}21222222^d$). This is termed a "*nodical* revolution of the Moon[a]," and must not be confounded with the "*synodical* revolution of the Moon." It is shorter than the latter, because the retrograde motion of the node upon the ecliptic brings the Moon into contact with it before she comes again into conjunction or opposition as the case may be. I must now refer to a singular effect produced by the retrocession of the nodes on the ecliptic. The Moon's synodical period, or the time which she occupies in passing from one conjunction or opposition to another, is $29^d\ 12^h\ 44^m\ 2{\cdot}87^s$ ($29{\cdot}5305887215^d$); 223 of these periods amount to $6585{\cdot}321^d$ ($18^y\ 10^d\ 7^h\ 43^m$); but 19 revolutions of the Sun with respect to the lunar node[b] (each of $346{\cdot}642^d$) are completed in $6585{\cdot}772^d$: the near coincidence of these two periods produces this obvious result; that eclipses recur in almost, though not quite, the same regular order after the completion of 19 synodical revolutions of the Moon's node. The difference between the two periods is $0{\cdot}451^d$, or $10^h\ 49{\cdot}6^m$; during which time the Sun describes an arc of $28' 6''$ relative to the lunar node.

It was probably a knowledge of this fact that enabled the ancient astronomers to predict the occurrence of great eclipses, since it is quite certain that they did so in more than one instance before the nature of eclipses was fully understood. This cycle was known to the Chaldæans as the *Saros*[c]. Diogenes Laërtius records 373 solar and 832 lunar eclipses observed in Egypt; and although his testimony is, generally, of no great value, yet it is very singular that this is just the proportion of solar and lunar eclipses visible above a given horizon within a certain period of

[a] Sometimes the *Draconic Period.*

[b] If the lunar nodes were immoveable the Sun would return to the same positions with respect to them every terrestrial tropical year; but this luni-nodical revolution of the Sun, if such an expression may be used, is less than the tropical year for the same reason that the *nodical* lunar month is less than the *synodical* one, the node receding to meet the Sun instead of remaining stationary. Since the lunar nodes travel at only $3' 10''$ per day, compared with the Sun's ecliptic motion of $59' 9''$, it follows that the nodes require $18{\cdot}6^d$ to get over the angular distance which the Sun does in 1^d. Deducting then $18{\cdot}6^d$ from $365{\cdot}242^d$ (the mean solar year), we get $346{\cdot}642^d$, as above, for the period of the Sun's return to the same lunar nodes.

[c] See *Eng. Cycl.*, art. *Saros.* It has been stated that the Chaldæans used a triple *Saros* of $54^y\ 31^d$ as more correct for purposes of prediction than a single one.

time (1200–1300 years)—a coincidence which cannot be accidental[d].

From what I have just said it might be imagined that a correct list of eclipses for 18·03 years would be sufficient for all purposes of calculation; as by adding the ecliptic period as many times as required, the period of an eclipse might be known at any distance of time. This would be nearly correct if an eclipse appeared under precisely the same circumstances as the one in the preceding or following period corresponding to it: but such is not the case[e]. An eclipse of the Moon, which in the year 565 A.D. was of 6 digits[f], was in the year 583 of 7 digits, and in 601 of nearly 8. In 908 the eclipse became total, and it remained so for about 12 periods, or until the year 1088: this eclipse continued to diminish until the commencement of the 15th century, when it totally disappeared in the year 1413. In a similar manner an eclipse of the Sun, which appeared at the North Pole in June 1295, became more southerly at each period. On Aug. 27, 1367, it made its first appearance in the north of Europe; in 1439 it was visible all over Europe; at its 19th appearance, in 1601, it was central in London; on May 5, 1818, it was visible at London, and was again nearly central at that place on May 15, 1836. At its 39th appearance, August 10, 1980, the Moon's shadow will have passed the equator, and, as the eclipse will take place near midnight, it will be invisible in Europe, Africa, and Asia. At every subsequent period the eclipse will go more and more towards the south, until, finally, at its 78th appearance on Sept. 30, 2665, it will go off at the South Pole of the Earth, and disappear altogether.

In the 18-year eclipse period, there usually happen 70 eclipses, of which 41 are solar and 29 are lunar. In any one year the greatest number that can occur is 7, and the least 2: in the former case 5 of them *may* be solar, and 2 lunar; in the latter

[d] *Hist. of Ast.*, L.U.K., p. 15.

[e] Halley found that if this period were added to the middle of any eclipse, the corresponding one might be predicted to within $1^h\ 30^m$. According as 4 or 5 leap-years intervene, the period of the Saros will be $18^y\ 10^d$ &c. or $18^y\ 11^d$ &c.

[f] A digit is the $\frac{1}{12}$ part of the diameter of the Sun or Moon; and of course an eclipse of 6 digits will be understood to be one in which $\frac{1}{2}$ the disc of the luminary is hidden. In the case of a lunar eclipse, when the magnitude is said to exceed 12 digits, it means that the Earth's shadow extends itself so many digits beyond the Moon's contour. The *Companion to the Almanac* for 1832 contains (p. 8) some useful memoranda about digits, and a description of the path of the central line at different periods of the year.

both *must* be solar. Under no circumstances can there be more than 3 lunar eclipses in 1 year, and in some years there are none at all. Though eclipses of the Sun are more numerous than those of the Moon in the proportion of 41 to 29 (say of 3 to 2), yet at any given place more lunar eclipses are visible than solar: because, whilst the former are visible over an entire hemisphere, the area of the Earth over which the latter are visible is in the case of total or annular eclipses a narrow strip, which cannot exceed 180 and is seldom more than 140 miles or so in breadth. In the case of partial eclipses of the Sun however the range of visibility is, it is true, much wider; for at every point of the Earth immersed in the penumbra more or less of the eclipse will be seen.

In a solar eclipse the Moon's shadow traverses the Earth at the rate of 1830 miles an hour, or rather more than half a mile per second. This corresponds to $30\frac{1}{2}$ miles per minute; Lalande's result is equivalent to 33·1 miles.

Du Séjour found that, counting from first to last, a solar eclipse at the equator may last $4^h\ 29^m\ 44^s$, and that at the latitude of *Paris* the maximum period is $3^h\ 26^m\ 22^s$, but that the interval of time during which the Sun will be centrally eclipsed is very small. The duration of the total obscuration is greatest when the Moon is in perigee and the Sun in apogee; for the apparent diameter of the Moon being then the greatest possible, while that of the Sun is the least possible, the excess of the former over the latter, upon which the totality depends, is at a maximum. Now the perigean diameter of the Moon $= 33'\ 31''$; the apogean diameter of the Sun $= 31'\ 30''$.

$$\therefore \quad \Delta = 33'\ 31'' - 31'\ 30'' = 2'\ 1''.$$

This then is theoretically the arc which has to be described by the Moon during the greatest possible continuance of the total phase, but in reality the ultimate result is complicated by the Sun's apparent motion Eastward and the Earth's axial rotation in the same direction. However, taking into consideration the rapid motion of the Moon, it will be readily understood that, under the most favourable circumstances, the Sun cannot remain totally eclipsed for more than a few minutes.

The duration of the obscuration in a total eclipse of the Sun

varies, *cæteris paribus*, with the latitude of the place of observation, and is greatest under the equator. Du Séjour[g] found that, under the most favourable circumstances, the greatest possible duration of the total phase at the equator was $7^m\ 58^s$, and that at the latitude of *Paris* it was $6^m\ 10^s$.

The duration of an annular eclipse is greatest when the Moon is in apogee and the Sun in perigee, for then the apparent diameter of the Sun is the greatest, whilst that of the Moon is the least possible, and consequently the excess of the former over the latter (upon which the annulus depends) is then at a maximum.

The perigean diameter of the Sun $= 32'\ 35''$. The apogean diameter of the Moon $= 29'\ 22''$.

$$\therefore\quad \Delta = 32'\ 35'' - 29'\ 22'' = 3'\ 13''.$$

This then is theoretically the arc which has to be described by the Moon during the greatest possible continuance of the annular phase, but, as before, some qualification is requisite in dealing with the facts which present themselves. Du Séjour found that under the most favourable circumstances the greatest possible duration of the annular phase at the equator[h] was $12^m\ 24^s$, and that at the latitude of *Paris*[i] it was $9^m\ 56^s$.

It may be desirable briefly to point out the reasons why the greatest possible duration of an annular eclipse exceeds that of a total one. They are 2 in number: 1st. Because the excess of the perigean diameter of the Sun over the apogean diameter of the Moon ($=3'\ 13''$) is greater than the excess of the perigean diameter of the Moon over the apogean diameter of the Sun ($=2'\ 1''$). 2nd. Because the motion of the Moon in apogee is much slower than it is in perigee.

From the above remarks it will be readily understood that though so many solar eclipses happen from time to time, yet the occurrence of an annular or total one at any particular locality is a very rare phenomenon. Thus, according to Halley[k], no total eclipse had been observed at London between March 20, 1140, and April 22, 1715 (O. S.), though during that interval the shadow of the Moon had frequently passed over other parts of Great Britain[l].

[g] *Mém. Acad. des Sciences*, 1777, p. 318.
[h] *Ibid.*, p. 317.
[i] *Ibid.*, p. 316.

[k] *Phil. Trans.*, vol. xxix. p. 245. 1715.
[l] It may here be noted that, according to recent investigations by Hind, the

The calculation of eclipses is a matter of considerable complexity. A paper by Woolhouse, in the supplement to the *Nautical Almanac* for 1836, and the chapters in Loomis's well-known work[m], may be named as the best guides in our language[n]. Much interesting historical matter concerning eclipses will be found in the Rev. S. J. Johnson's *Eclipses, Past and Present.*

Total solar eclipse of Feb. 3, 1916, will not be visible as such in England, though a statement to that effect may occasionally be met with. On June 30, 1954, occurs the next Total eclipse which will be visible in Great Britain: this will be seen at the northernmost of the Shetland Isles. The eclipse of Aug. 11, 1999, is the next that will be visible as a Total one in England itself. The line of totality will pass across Cornwall and Devonshire. Hind, in connection with the calculations from which these particulars were derived, ascertained that the eclipse of 1140 was not centrally visible in London. The line of totality crossed the Midland Counties, and did not approach London nearer than Northamptonshire. (See letters by Hind in *Ast. Reg.*, vol. vii. p. 87, April 1869, and vol. ix. p. 209, Sept. 1871; also a paper by the Rev. S. J. Johnson in *Month. Not.*, vol. xxxii. p. 332. 1872.)

[m] *Practical Astronomy*, pp. 226–90.

[n] It is recorded by Rittenhouse that in his early days he calculated eclipses on his plough-handle.

CHAPTER II.

ECLIPSES OF THE SUN.

Grandeur of a Total Eclipse of the Sun.—How regarded in ancient times.—Effects of the progress of Science.—Chief phenomena seen in connexion with Total Eclipses.—Change in the colour of the sky.—The obscurity which prevails.—Effect noticed by Piola.—Physical explanation.—Baily's Beads.—Extract from Baily's original memoir.—Probably due to irradiation.—Supposed to have been first noticed by Halley in 1715.—His description.—The Corona.—Hypothesis advanced to explain its origin.—Probably caused by an atmosphere around the Sun.—Remarks by Grant.—First alluded to by Philostratus.—Then by Plutarch.—Corona visible during Annular Eclipses.—The Red Flames.—Remarks by Dawes.—Physical cause unknown.—First mentioned by Stannyan.—Note by Flamsteed.—Observations of Vassenius.—Aspect presented by the Moon.—Remarks by Arago.

A TOTAL eclipse of the Sun is a most imposing spectacle, especially when viewed from the summit of a lofty mountain. Words can but inadequately describe the grandeur and magnificence of the scene. On all sides indications are afforded that something unusual is taking place. At the moment of totality the darkness is sometimes so intense that the brighter stars and planets are seen, birds go to roost, flowers close, and the face of nature assumes an unearthly cadaverous hue; while not the least striking thing is the sudden and frequently considerable fall that takes place in the temperature of the atmosphere as the time of the greatest obscuration draws near.

"During the early history of mankind, a total eclipse of the Sun was invariably regarded with a feeling of indescribable terror, as an indication of the anger of the offended Deity, or the presage of some impending calamity; and various instances are on record of the (supposed) extraordinary effects produced by so unusual an event. In a more advanced state of society, when Science had

N 2

begun to diffuse her genial influence over the human mind, these vain apprehensions gave place to juster and more ennobling views of nature; and eclipses generally came to be looked upon as necessary consequences flowing from the uniform operation of fixed laws, and differing from the ordinary phenomena of nature only in their less frequent occurrence. To astronomers they have in all ages proved valuable in the highest degree, as tests of great delicacy for ascertaining the accuracy of their calculations relative to the place of the Moon, and hence deducing a further improvement of the intricate theory of her movements. In modern times, when the physical constitution of the celestial bodies has attracted the attention of many eminent astronomers, observations of eclipses have disclosed several interesting facts, which have thrown considerable light on some important points of inquiry respecting the Sun and Moon[a]."

Among the Hindus a singular custom exists[b]. When during a solar eclipse the black disc of our satellite is seen advancing over the Sun, the natives believe that the jaws of some monster are gradually eating it up. They then commence beating gongs, and rending the air with the most discordant screams of terror and shouts of vengeance. For a time their efforts are productive of no good result—the eclipse still progresses. At length, however, the terrific uproar has the desired effect on the voracious monster; it appears to pause, and then, like a fish that has nearly swallowed a bait and then rejects it, it gradually disgorges the fiery mouthful. When the Sun is quite clear of the great dragon's mouth, a shout of joy is raised, and the poor natives disperse, extremely self-satisfied on account of their having (as they suppose) so successfully relieved their deity from his late perils. For us times have now happily altered. *We* do not look on a total eclipse of the Sun as a dire calamity, but merely as one of the ordinary effects resulting from the due working of those laws by which the Supreme Being wills to govern the universe.

[a] Grant, *Hist. Phys. Ast.*, p. 359. The truth of the last sentence of this extract is now more striking than it was in 1852.

[b] In my first edition I wrote "is said to exist," but the following paragraph, cut from a newspaper in 1868, and relating to the great eclipse of Aug. 18, 1868, will show that the present reading of the text is preferable:—"Tuesday was a general holiday, and the natives signified the swallowing of the sun by a demon by the usual drumming, shrieking, and blowing of shells, with offerings of rice."

An eclipse of the Sun may be either *partial*, *annular*, or *total*: it is partial when only a portion of the Moon's disc intervenes between the Sun and the observer on the Earth; annular, when the Moon's apparent diameter is less than the Sun's, so that when the former is projected on the latter it is not sufficiently large completely to cover it,—an annulus, or ring of the Sun, being left unobscured; and total when the Moon's apparent diameter is greater than that of the Sun, which is, therefore, wholly obscured. In an annular eclipse, when the centre of the Sun and Moon exactly coincide, it is said to be *central and annular*—the Sun appearing, for a very short time, as a brilliant ring of light around the dark body of the Moon.

I shall now proceed to describe the principal phenomena which are usually witnessed in connexion with solar eclipses.

Not the least remarkable is the almost invariable change of colour which the sky undergoes. Halley, in his account of the eclipse of 1715, says: "When the eclipse was about 10 digits (that is, when about $\frac{5}{6}$ of the solar diameter was immersed), the face and colour of the sky began to change from a perfect serene azure blue to a more dusky livid colour, intermixed with a tinge of purple, and grew darker and darker till the total immersion of the Sun [c]."

It has also been found that whilst the sky changes colour during the progress of an eclipse, similar effects are also produced upon terrestrial objects. This seems to have been noticed as far back as 840 A.D. [d] Kepler mentions that during the solar eclipse which happened in the autumn of 1590, the reapers in Styria noticed that everything had a yellow tinge [e]. Similar effects have also been described in modern times [f].

The darkness which prevails during a total eclipse of the Sun is not usually so considerable as might be expected. It is, however, subject to much variation. Ferrer, speaking of the eclipse of 1806, says that at the time of total obscuration "without doubt the light was greater than that of the full Moon [g]." In general

[c] *Phil. Trans.*, vol. xxix. p. 247. 1715. Arago gives an elaborate explanation of this. *Pop. Ast.*, vol. ii. p. 358, Eng. ed.

[d] *Ad Vitellionem Paralipomena*, p. 294.

[e] *Ibid.*, p. 303.

[f] *Mem.* R.A.S., vol. xv. pp. 12, 14, and 15, 1846; xxi. *passim*, 1853; *Annuaire*, 1846, p. 291, &c.

[g] *Trans. Amer. Phil. Soc.*, vol. vi. p. 266. 1809.

it has been found that the darkness is sufficiently great to prevent persons from reading, though exceptions to this rule have been known. The faint illumination which exists at the moment of the totality is due to light reflected from those regions of the atmosphere which are still exposed to the direct rays of the Sun. The corona (which will presently be described) also, no doubt, assists a little in producing the effect. The degree of obscuration will also vary according as the observer is or is not deeply immersed in the lunar shadow—a fact first pointed out by Halley [h].

As previously remarked, a solar eclipse of large magnitude and still more a Total eclipse is always accompanied by a decided decrease in the temperature of the air (in the shade). Mr. G. J. Symons from observations in 1858, 1860, and 1870, concludes that the air is coldest about ½ hour after the time of the conjunction of the Sun and Moon.

In the case of the eclipse of 1842, it was remarked by Piola at Lodi, and by O. Struve at Lipesk, that although the obscurity was such that stars of the 2nd and 3rd magnitudes ought to have been visible, yet only those of the 1st magnitude were actually seen [i]. M. Belli explains this curious fact by reference to a physiological principle. He remarks that during the short interval of total obscuration the eye has not sufficient time to recover from the dazzling effect of the Sun's rays, and consequently is unable to take advantage of the obscurity which actually prevails [k]. The suddenness with which the light succeeds the darkness after a total eclipse of the Sun is well known. Halley suggested 2 explanations of the phenomenon. 1st. That previously to the total obscuration the pupil of the eye might be very much contracted by viewing the Sun, and consequently the organ of vision would be less likely to suffer by the effulgence of the light than at the instant of emersion, when the pupil had again expanded. 2nd. That, as the Eastern margin of the Moon, at which the Sun disappeared, had been exposed for a fortnight to the direct action of the solar rays, the heat generated during this period might cause vapours to ascend in the lunar atmosphere, which, by their interposition

h *Philosophical Trans.*, vol. xxix. p. 250. 1715.

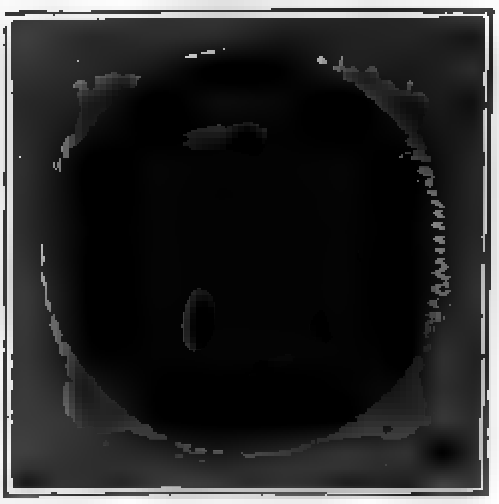
i *Giorn. dell' Ist. Lomb.*, vol. iv. p. 341; *Bibliothèque Universelle de Genève*, vol. xliv. p. 368.

k *Giorn. dell' Ist. Lomb.*, vol. iv. p. 341.

between the Sun and the Earth, would have the effect of tempering the effulgence of the solar rays passing through them. On the other hand, the Western margin of the Moon, at which the Sun re-appeared, had just experienced a night of equal length, during which the vapours suspended in the lunar atmosphere had been undergoing a course of precipitation upon the Moon's surface under a process of cooling. In this case, therefore, the solar rays would meet with less obstruction in passing through the lunar atmosphere, and, consequently, it was reasonable to suppose that they would produce a more intense effect[l]. The second hypothesis requires us to suppose the presence of a lunar atmosphere, the existence of which modern observation tends to disprove. The first is doubtless the true explanation.

When the disc of the Moon advancing over that of the Sun has reduced the latter to a thin crescent, it is usually noticed that immediately before the beginning and after the end of complete obscuration, the crescent appears as a band of brilliant points, separated by dark spaces so as to give it the appearance of a string of beads. No satisfactory explanation has yet been given of this phenomenon, though the most probable hypothesis is that which refers its origin to the effect of irradiation. It is often stated that the effects observed are due to the projection of some of the mountains of our satellite upon the solar disc. But this explanation is not altogether satisfactory.

Fig. 76.



"BAILY'S BEADS."

These phenomena are generally known as *Baily's Beads*, having received their name from the late Mr. Francis Baily, who was the first to describe them in detail[m]. His original memoir was published in 1836, and from it I make the following quotation:—

"When [previous to the totality] the cusps of the Sun were about 40° asunder, a row of lucid points, like a string of bright beads, irregular in size and distance from

[l] *Phil. Trans.*, vol. xxix. p. 248. 1715.
[m] They were noticed long before his time.

each other, *suddenly* formed round that part of the circumference of the Moon that was about to enter, or which might be considered as having just entered, on the Sun's disc. Its formation indeed was so rapid, that it presented the appearance of having been caused by the ignition of a train of gunpowder. This I intended to note as the correct time of the formation of the annulus, expecting every moment to see the thread of light completed round the Moon, and attributing this serrated appearance of the Moon's limb (as others had done before me) to the lunar mountains, although the remaining portion of the Moon's circumference was comparatively smooth and circular, as seen through the telescope. My surprise, however, was great on finding that these luminous points, as well as the dark intervening spaces, increased in magnitude, some of the contiguous ones appearing to run into each other like drops of water; for the rapidity of the change was so great, and the singularity of the appearance so fascinating and attractive, that the mind was for the moment distracted and lost in the contemplation of the scene, so as to be unable to attend to every minute occurrence. Finally, as the Moon pursued her course, these dark intervening spaces (which, at their origin, had the appearance of lunar mountains in high relief, and which still continued attached to the Sun's border) were stretched out into long, black, thick parallel lines, forming the limbs of the Sun and the Moon; when, all at once, they *suddenly* gave way, and left the circumferences of the Sun and Moon in those points, as in the rest, comparatively smooth and circular, and the Moon perceptibly advanced on the face of the Sun [n]."

Mr. Baily then goes on to describe the appearances which he saw after the total obscuration; they were, however, substantially the same as those recorded above.

The earliest account of the phenomenon of the beads is contained in Halley's memoir on the total eclipse of 1715. He says: "About 2 minutes before the total immersion, the remaining part of the Sun was reduced to a very fine horn, whose extremities seemed to lose their acuteness, and *to become round like stars;* and, for the space of about a quarter of a minute, a small piece of the Southern horn of the eclipse seemed to be *cut off from the rest* by a good interval, and appeared like an oblong star rounded at both ends [o]." The first annular eclipse in which it appears that any beads were seen was that of Feb. 18, 1736–7, observed by Maclaurin [p].

One of the most interesting appearances seen during a total eclipse of the Sun is the *corona*, or halo of light which surrounds the Moon. It usually appears 3 or 4 seconds previous to the total extinction of the Sun's light, and continues visible for about the same interval of time after its reappearance. In general, it may be compared to the nimbus commonly painted around the heads of

[n] *Mem.* R.A.S., vol. x. p. 5. 1838. [o] *Phil. Trans.*, vol. xxix. p. 248. 1715.
[p] *Phil. Trans.*, vol. xl. p. 177. 1737.

the Virgin Mary, the Apostles, &c. Different explanations have been advanced to account for this phenomenon: Kepler thought it due to the presence of an atmosphere round the Moon[q]: La Hire suggested that it might be produced by the reflection of the solar rays from the inequalities of the Moon's surface, contiguous to the edge of her disc, combined with their subsequent passage through the Earth's atmosphere[r]; the late Professor Baden Powell once conducted a series of experiments which tended strongly to support the idea that refraction was the cause of it[s]: on the whole, however, it is now tolerably clear that it is due to something in the nature of *an atmosphere about the Sun.* "Its round figure, its nebulous structure, and its gradually diminishing density onwards, are all favourable to the supposition of its being due to an elastic fluid encompassing the solar orb, and gravitating everywhere towards its centre. It is true that precisely similar results would ensue from the existence of an atmosphere about the Moon; but, in fact, there is no reason to suppose that the Moon possesses an atmosphere capable of producing an appreciable effect. On the other hand, the hypothesis of a solar atmosphere is not only warranted by the analogy of the other bodies of the planetary system, but is also supported by evidence of a positive nature, derived from observations on the physical constitution of the Sun. The changes presented by that body when viewed in a telescope can only be consistently accounted for by the supposition of two dissimilar envelopes of matter suspended in a transparent atmosphere at different altitudes above its surface[t]." Delisle conjectured that the luminous ring might be occasioned by the diffraction of the solar rays which pass near the Moon's edge[u]. Sir David Brewster shewed that this theory, though ingenious, is quite untenable[x]. Baxendell is disposed to regard the corona as a nebulous ring round the Sun which reflects solar light, and possibly its more distant and radiated portion may have some such origin.

Judged by photographic results, the solar corona is *very* much fainter than the Moon, for whilst its outer portion has been found

[q] *Ad Vitell. Paralipom.*, p. 302; *Epit. Astron.*, p. 893.
[r] *Mém. Acad. des Sciences*, 1715, p. 161 *et seq.*
[s] *Mem.* R.A.S., vol. xvi. p. 301. 1847.
[t] Grant, *Hist. Phys. Ast.*, p. 389.
[u] *Mém. Acad. des Sciences*, 1715, p. 166 *et seq.*
[x] *Edin. Encyc.*, art. *Astronomy.*

to fail utterly to make any impression on a plate after an exposure of 5 seconds, the Moon has been photographed perfectly in 0·1 to 0·2 seconds. Moreover Federow in 1842; Swan and Chevallier in 1851; and Lespiault, Burat, and Cuillier in 1860, all observed, and specially recorded, that *no shadow* was cast by the corona.

The earliest historical allusion to the corona is made by Philostratus. He mentions that the death of the Emperor Domitian had been 'announced' previously by a total eclipse of the sun. "In the heavens there appeared a prodigy of this nature. A certain *corona*, resembling the *Iris*, surrounded the orb of the Sun and obscured his light[y];" (*i. e.* it appeared coincidently with the total obscuration of his light). Plutarch is still more precise in his allusion. Speaking of a total eclipse of the Sun which had recently happened, he endeavours to shew why the darkness arising from such phenomena is not so profound as that of night. He begins by assuming, as the basis of his reasoning, that the Earth greatly exceeds the Moon in size, and, after citing some authorities, he goes on to say:—"Whence it happens that the Earth, on account of its magnitude, entirely conceals the Sun from our sight. . . . But even although the Moon should at any time *hide the whole of the Sun*, still the eclipse is deficient in duration, as well as amplitude, for a peculiar effulgence is seen around the circumference, which does not allow the obscurity to become very intense or complete." (Ἀλλὰ περιφαίνεταί τις αὐγὴ περὶ τὴν ἴτυν, οὐκ ἐῶσα βαθεῖαν γίνεσθαι τὴν σκιὰν καὶ ἄκρατον[z].) The luminous ring seems to have been noticed by Clavius during the eclipse of April 9, 1567: he thought that it was merely the uncovered margin of the Sun's disc; but Kepler shewed that this was impossible.

There are one or two well-authenticated instances of the corona being visible during partial eclipses of the Sun. In 1842, M. D'Hombre Firmas, at Alais, which was contiguous to, though not actually in the path of the shadow, states that, "every one remarked the circle of pale light which encompassed the Moon when she almost covered the Sun[a]." Several observers of this eclipse noticed that the ring at first appeared to be brightest on

[y] *Life of Apollonius of Tyana*, by Philostratus, Bk. viii. cap. 22. The passage will be found quoted in *Ast. Nach.*, vol. lxxvii. No. 1838, March 31, 1871.

[z] Plut., *Opera Mor. et Phil.* vol. ix. p. 682. Ed. Lipsiæ. 1778.

[a] *Annuaire*, 1846, p. 339.

the side of the solar disc which was first covered by the Moon, but that previously to the close of the total phase, it was brightest at the part where the Sun was about to reappear [b].

Not the least beautiful phenomena seen during a total solar eclipse are the "Red Flames," which become visible around the margin of the Moon's disc immediately after the commencement of the total phase. Mr. Dawes has so minutely described them, as they appeared to him in July 1851, that I cannot do better than quote his words. He says:—

"Throughout the whole of the quadrant from north to east there was no visible protuberance, the corona being uniform and uninterrupted. Between the east and south points, and at an angle of about 115° from the north point, appeared a large red prominence of a very regular conical form. When first seen it might be about 1½′ in altitude from the edge of the Moon, but its length diminished as the Moon advanced.

"The position of this protuberance may be inaccurate to a few degrees, being more hastily noticed than the others. It was of a deep rose colour, and rather paler near the middle than at the edges.

"Proceeding southward, at about 145° from the north point, commenced a few ridge of red prominences, resembling in outline the tops of a very irregular range hills. The highest of these probably did not exceed 40″. This ridge extended through 50° or 55°, and reached, therefore, to about 197° from the north point, its base being throughout formed by the sharply-defined edge of the Moon. The irregularities at the top of the ridge seemed to be permanent, but they certainly appeared to undulate from the west towards the east; probably an atmospheric phenomenon, as the wind was in the west.

"At about 220° commenced another low ridge of the same character, and extended to about 250°, less elevated than the other, and also less irregular in outline, except that at about 225° a very remarkable protuberance rose from it to an altitude of 1½′, or more. The tint of the low ridge was a rather pale pink; the colour of the more elevated prominence was decidedly deeper, and its brightness much more vivid. In form it resembled a *dog's tusk*, the convex side being northwards, and the concave to the south. The apex was somewhat acute. This protuberance, and the low ridge connected with it, were observed and estimated in height towards the end of the totality.

"A small double-pointed prominence was noticed at about 255°, and another low one with a broad base at about 263°. These were also of the rose-coloured tint, but rather paler than the large one at 225°.

"Almost directly preceding, or at 270°, appeared a bluntly triangular pink body, *suspended*, as it were, in the corona. This was separated from the Moon's edge when first seen, and the separation increased as the Moon advanced. It had the appearance of a large conical protuberance, whose base was hidden by some intervening soft and ill-defined substance, like the upper part of a conical mountain, the lower portion of which was obscured by clouds or thick mist. I think the apex of this object must

[b] *Mem.* R.A.S., vol. xv. p. 16. 1846.

have been at least 1′ in altitude from the Moon's limb when first seen, and more than 1½′ towards the end of total obscuration. Its colour was pink, and I thought it paler in the middle.

"To the north of this, at about 280° or 285°, appeared the most wonderful phenomenon of the whole. A red protuberance, of vivid brightness and very deep tint, arose to a height of, perhaps, 1½′ when first seen, and increased in length to 2′, or more, as the Moon's progress revealed it more completely. In shape it somewhat resembled a *Turkish cimeter*, the northern edge being convex, and the southern concave. Towards the apex it bent suddenly to the south, or upwards, as seen in the telescope. Its northern edge was well defined, and of a deeper colour than the rest, especially towards its base. I should call it a *rich carmine*. The southern edge was less distinctly defined, and decidedly paler. It gave me the impression of a somewhat conical protuberance, partly hidden on its southern side by some intervening substance of a soft or flocculent character. The apex of this protuberance was paler than the base, and of a purplish tinge, and it certainly had a flickering motion. Its base was, from first to last, sharply bounded by the edge of the Moon. To my great astonishment, this marvellous object *continued visible for about* 5 *seconds*, as nearly as I could judge, *after the Sun began to reappear*, which took place many degrees to the south of the situation it occupied on the Moon's circumference. It then rapidly faded away, *but it did not vanish instantaneously*. From its extraordinary size, curious form, deep colour, and vivid brightness, this protuberance absorbed much of my attention; and I am, therefore, unable to state precisely what changes occurred in the other phenomena towards the end of the total obscuration.

"The arc from about 283° to the north point was entirely free from prominences, and also from any roseate tint."

Astronomers were long unable to determine the nature of these rose-coloured emanations; but it is now accepted that they belong to the Sun and consist of gaseous matter (chiefly hydrogen) in an incandescent state rushing upwards with inconceivable velocity.

One of these prominences, measured by De La Rue in 1860, was 44,000 miles in vertical height above the Sun's surface.

Julius Firmicus, speaking of the eclipse of July 17, 334, makes a remark which may apply to this phenomenon; otherwise the earliest recorded account of the Red Flames is by Captain Stannyan, who observed them at Berne during the total eclipse of 1706. He writes to Flamsteed:—

"That the Sun was totally darkened there for 4½ minutes of time; that a fixed star and a planet appeared very bright; and *that his getting out of his eclipse was preceded by a blood-red streak of light from its left limb, which continued not longer than 6 or 7 seconds of time;* then part of the Sun's disc appeared all of a sudden, as bright as Venus was ever seen in the night; nay, brighter; and in that very instant gave a light and shadow to things as strong as the Moon uses to do[c]."

[c] *Phil. Trans.*, vol. xxv. p. 2240. 1706.

On this communication Flamsteed remarks:—

"The Captain is the first man I ever heard of that took notice of a red streak preceding the emersion of the Sun's body from a total eclipse. And I take notice of it to you [the Royal Society], because it infers that the Moon has an atmosphere; and its short continuance, if only 6 or 7 seconds' time, tells us that its height was not more than 5 or 6 hundredths part of her diameter [d]."

The Red Flames were seen by Halley, Louville [e], and C. Hayes in 1715, and afterwards by Vassenius, at Göttenberg, who says:—

"But what seemed in the highest degree worthy, not merely of observation, but also of the attention of the illustrious Royal Society, were some reddish spots which appeared in the lunar atmosphere *without* the periphery of the Moon's disc, amounting to 3 or 4 in number, one of which was larger than the other, and occupied a situation about midway between the south and west. These spots seemed in each instance to be composed of 3 smaller parts or cloudy patches of unequal length, having a certain degree of obliquity to the periphery of the Moon. Having directed the attention of my companion to the phenomenon, who had the eyes of a lynx, I drew a sketch of its aspect; but while he, not being accustomed to the use of the telescope, was unable to find the Moon, I, again with great delight, perceived the same spot, or, if you choose, rather the invariable cloud occupying its former situation in the atmosphere near the Moon's periphery [f]."

A "Red-Flame" of a *greenish-blue* tinge has been noticed. This Arago considered to be an effect of contrast.

The Red Flames have also been noticed in annular eclipses, as in that of 1737, observed by Maclaurin, which appears to be the earliest in which the phenomenon was seen [g]; and in partial eclipses, of which that of 1605, observed by Kepler, is probably the first [h].

The aspect presented by the Moon during eclipses of the Sun is frequently very singular. Kepler stated that the Moon's surface is occasionably distinguishable by a ruddy hue [i]. Baily, in his account of the annular eclipse of 1836, states, that "previous to the formation of the ring, the face of the Moon was perfectly black; but on looking at it through the telescope, *during the annulus*, the circumference was tinged with a *reddish purple colour*, which extended over the whole disc, but increased in density of colour, according to the proximity to the centre, so as to be in that part nearly black [k]." Vassenius in 1733 and Ferrer in 1806 are the only observers who state that they have seen the irregularities

[d] *Phil. Trans.*, vol. xxv. p. 2241. 1706.
[e] *Mem.* R.A.S., vol. xxi. p. 90. 1853.
[f] *Phil. Trans.*, vol. xxviii. p. 135. 1733.
[g] *Phil. Trans.*, vol. xl. p. 181. 1737.
[h] *De Stellâ Novâ*, p. 116.
[i] *Epit. Astron.*, p. 895.
[k] *Mem.* R.A.S., vol. x. p. 17. 1838.

in the Moon's surface during a central eclipse, whether total or annular[l]. Arago and others tried to do so in 1842, but failed. The fact that the lunar inequalities sometimes are seen and at other times are not seen is doubtless owing to meteorological causes.

In 1842 Arago saw the dark contour of the Moon projected upon the bright sky 40^m after the commencement of the eclipse. He ascribes the phenomenon to the projection of the Moon upon the solar atmosphere, the brightness of which, by an effect of contrast, rendered the outline of the Moon's dark limb discernible[m]. The phenomenon appears to be a rare one: at least it is recorded by only 3 recent observers[n].

On several occasions attempts have been made to detect the Moon's shadow in the course of its passage over the surface of the Earth. Airy in 1851 succeeded in observing it, but he failed in 1842, in which year, however, Plana and Forbes were more fortunate. The difficulty arises from the immense velocity of the shadow—30½ miles per minute. The earliest historical record of the eclipse-shadow being seen occurs in Duillier's account of the eclipse of May 12, 1706[o].

According to M. Laussedat, one of the horns of the solar crescent in 1860 appeared for a short time rounded and truncated. The other horn was contracted nearly to a point, and a small patch of light wholly detached was visible beyond the extremity of this cusp.

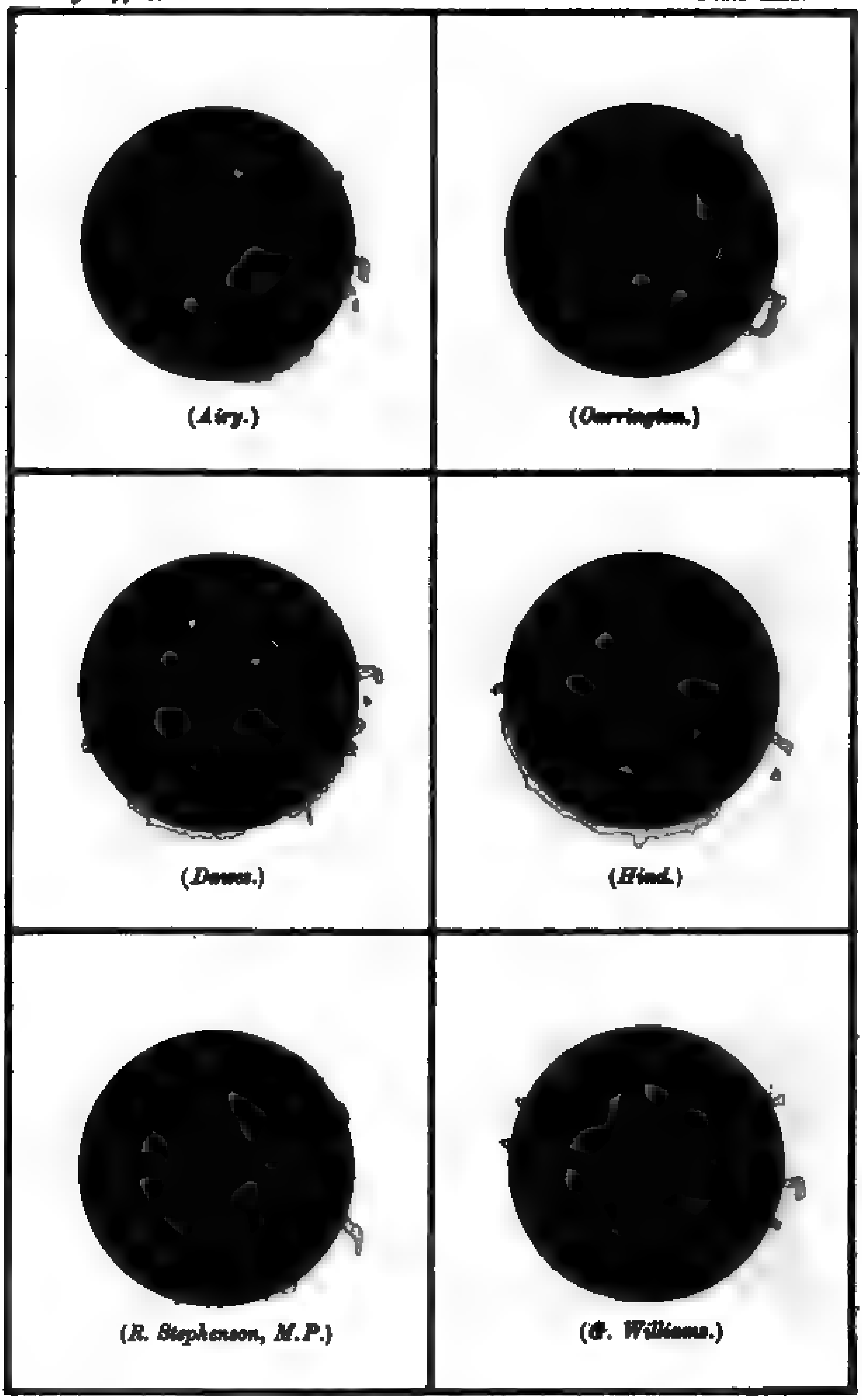
[l] *Phil. Trans.*, vol. xxxviii. p. 135, 1733; *Trans. Amer. Phil. Soc.*, vol. vi. p. 267. 1809.

[m] *Annuaire*, 1846, p. 372.

[n] Noble, Pratt, and Neison, *Month. Not.*, vols. xxvii. p. 185, March 1867, and xxxiii. pp. 468 and 577, June, &c. 1873; *Ast. Reg.*, vol. xiii. p. 9, Jan. 1875.

[o] *Mém. Acad. des Sciences*, 1706, p. 113 (Hist.); *Phil. Trans.*, vol. xxv. p. 2243. 1706.

Figs. 77-82. Plate XII.



THE TOTAL ECLIPSE OF THE SUN OF JULY 28, 1851.

VIEWS OF THE RED FLAMES.

CHAPTER III.

THE TOTAL ECLIPSE OF THE SUN

OF JULY 28, 1851.

Observations by Airy.—By Hind.—By Lassell.

NOT the least interesting of the total eclipses of the Sun that have occurred within the last few years was that of July 28, 1851. Though not visible in England, it was seen to great advantage in Sweden, to which country many astronomers went at the time for the purpose of observing the eclipse. The following remarks are from the pen of Sir G. B. Airy, the Astronomer Royal, who observed the eclipse at Göttenberg:—

"The approach of the totality was accompanied with that indescribably mysterious and gloomy appearance of the whole surrounding prospect, which I have seen on a former occasion. A patch of clear blue sky in the zenith became purple-black while I was gazing on it. I took off the higher power with which I had scrutinized the Sun, and put on the lowest power (magnifying about 34 times). With this I saw the mountains on the Moon perfectly well. I watched carefully the approach of the Moon's limb to that of the Sun, which my graduated dark glass enabled me to see in great perfection: I saw both limbs perfectly well defined to the last, and saw the line becoming narrower, and the curves becoming sharper, without any distortion or prolongation of the limbs. I saw the Moon's serrated limb advance up to the Sun's, and the light of the Sun glimmering through the hollows between the mountain peaks, and saw these glimmering spots extinguished one after another in extremely rapid succession, but without any of the appearances which Mr. Baily has described. . . . . I have no means of ascertaining whether the darkness really was greater in the eclipse of 1842. I am inclined to think, that in the wonderful, and, I may say, appalling obscurity, I saw the grey granite hills, within sight of Hvaläs, more distinctly than the darker country surrounding the Superga. But whether, because in 1851 the sky was much less clouded than in 1842 (so that the transition was from a more luminous state of sky, to a darkness nearly equal in both cases), or from whatever cause, the suddenness of the darkness in 1851 appeared to be much more striking than in 1842. My friends, who were on the upper rock, to which the path was very good, had great difficulty in descending. A candle had been lighted in a

lantern, about a quarter of an hour before the totality; Mr. Hasselgren was unable to read the minutes of the chronometer's face without having the lantern held close to the chronometer.

"The corona was far broader than that which I saw in 1842; roughly speaking, its breadth was a little less than the Moon's diameter, but its outline was very irregular. I did not remark any beams projecting from it which deserved notice as much more conspicuous than the others; but the whole was beamy, radiated in structure, and terminated (though very indefinitely) in a way which reminded me of the ornament frequently placed round a mariner's compass. Its colour was white, and resembling that of Venus. I saw no flickering or unsteadiness of light. It was not separated from the Moon by any dark ring, nor had it any annular structure: it looked like a radiating luminous cloud behind the Moon. . . . The form of the prominences was most remarkable. One reminded me of a boomerang. Its colour, for at least two-thirds of its width, from the convexity to the concavity, was full lake red; the remainder was nearly white. The most brilliant part of it was the swell farthest from the Moon's limb; this was distinctly seen by my friends and myself with the naked eye. I did not measure its height; but judging generally by its proportion to the Moon's diameter, it must have been 3′. This estimation, perhaps, belongs to a later period of the eclipse. . . . It was impossible to see the changes that took place in the prominences, without feeling the conviction that they belonged to the Sun, and not to the Moon.

"I again looked round, when I saw a scene of unexpected beauty. The southern part of the sky, as I have said, was covered with uniform white cloud; but in the northern part were detached clouds, upon a ground of clear sky. This clear sky was now strongly illuminated to the height of 30° or 35°, and through almost 90° of azimuth, with rosy red light shining through the intervals between the clouds. I went to the telescope, with the hope that I might be able to make the polarization-observation (which, as my apparatus was ready to my grasp, might have been done in 3 or 4 seconds), when I saw the *sierra*, or rugged line of projections, had arisen. This *sierra* was more brilliant than the other prominences, and its colour was nearly scarlet. The other prominences had perhaps increased in height, but no additional new ones had arisen. The appearance of this *sierra*, nearly in the place where I expected the appearance of the Sun, warned me that I ought not now to attempt any other physical observation. In a short time the white Sun burst forth, and the corona, and every other prominence, vanished.

"I withdrew from the telescope, and looked round. The country seemed, though rapidly, yet half unwillingly, to be recovering its usual cheerfulness. My eye, however, was caught by a duskiness in the south-east, and I immediately perceived that it was the eclipse-shadow in the air, travelling away in the direction of the shadow's path. For at least 6 seconds this shadow remained in sight, far more conspicuous to the eye than I had anticipated [a]."

Mr. J. R. Hind watched the eclipse at Rævelsberg, near Engelholm. He says:—

"The moment the Sun went out the corona appeared; it was not very bright, but this might arise from the interference of an extremely light cloud of the *cirrus* class

[a] *Mem.* R.A.S., vol. xxi. p. 5, 1853.

which overspread the Sun at the time. The corona was of the colour of tarnished silver, and its light seemed to fluctuate considerably, though without any appearance of revolving. Rays of light, the *aigrettes*, diverged from the Moon's limb in every direction, and appeared to be shining through the light of the corona. In the telescope many rose-coloured flames were noticed; one, far more remarkable than the rest, on the western limb, could be distinguished without any telescopic aid; it was curved near its extremity, and continued in view 4 *seconds after the Sun had disappeared*, i.e., after the extinction of 'Baily's beads,' which phenomena were very conspicuous in this eclipse, particularly before the commencement of the totality. In this case they were clearly to be attributed to the existence of many mountains and valleys along the Moon's edge, the Sun's light shining through the valleys and between the mountain ridges, so as to produce the appearance of luminous drops or beads, which continued visible some seconds. The colour of the 'flames' was a full rose red at the borders, gradually fading off, towards the centres, to a very pale pink. Along the southern limb of the Moon, for 40° or upwards, there was a constant succession of very minute rose-coloured prominences, which appeared to be in a state of undulation, though without undergoing any material change of form. An extremely fine line, of a violet colour, separated these prominences from the dark limb of the Moon. The surface of our satellite, during the total eclipse, was purplish in the telescope; to the naked eye it was by no means very dark, but seemed to be faintly illuminated by a purplish grey light of uniform intensity, on every part of the surface.

"The aspect of nature during the total eclipse was grand beyond description. A diminution of light over the Earth was perceptible a quarter of an hour after the beginning of the eclipse; and about ten minutes before the extinction of the Sun, the gloom increased very perceptibly. The distant hills looked dull and misty, and the sea assumed a dusky appearance, like that it presents during rain; the daylight that remained had a yellowish tinge, and the azure blue of the sky deepened to a purplish violet hue, particularly towards the north. But notwithstanding these gradual changes, the observer could hardly be prepared for the wonderful spectacle that presented itself, when he withdrew his eye from the telescope, after the totality had come on, to gaze around him for a few seconds. The southern heavens were then of a uniform purple-grey colour, the only indications of the Sun's position being the luminous corona, the light of which contrasted strikingly with that of the surrounding sky. In the zenith and north of it, the heavens were of a purplish-violet, and appeared very near; while in the north-west and north-east, broad bands of yellowish crimson light, intensely bright, produced an effect which no person who witnessed it can ever forget. The crimson appeared to run over large portions of the sky in these directions, irrespective of the clouds. At higher altitudes the predominant colour was purple. All nature seemed to be overshadowed by an unnatural gloom. The distant hills were hardly visible, the sea turned lurid red, and persons standing near the observer had a pale livid look, calculated to produce the most painful sensations. The darkness, if it can be so termed, had no resemblance to that of night. At various places within the shadow, the planets Venus, Mercury, and Mars, and the brighter stars of the first magnitude, were plainly seen during the total eclipse. Venus was distinctly seen at Copenhagen, though the eclipse was only partial in that city; and at Dantzic she continued in view 10 minutes after the Sun had reappeared. Animals were frequently much affected. At Engelholm, a calf which commenced lowing violently as the gloom deepened, and lay down before the totality had

commenced, went on feeding quietly enough very soon after the return of daylight. Cocks crowed at Elsinborg, though the Sun was only hidden there 30 seconds, and the birds sought their resting-places, as if night had come on[b]."

Mr. W. Lassell, who stationed himself near the Trollhätten Falls, thus describes the total obscuration:—

"I may attempt, but I cannot accomplish, an adequate description of the marvellous appearances, and their effect upon the mind, which were crowded into this small space of 3½ minutes,—an interval which seemed to fly as if it were composed of seconds and not of minutes! Perhaps a naked-eye observer would more fully grasp the awful effect of the sudden extinguishment of light,—the most overpowering of these appearances,—for, my eye being directed through the telescope, I must have been less, though sufficiently, struck with the unprecedented sensation of such instantaneous gloom. The amount of darkness may be appreciated from the fact that, on withdrawing my eye from the telescope, I could neither see the second hands of my watch, nor the paper sufficiently to write the time down; and was only able to do so by going to the candle, which I had by me burning on the table. Probably the suddenness of the gloom, not giving time for the expansion of the pupil of the eye, increased the sensation of apparent darkness; as I was obliged to repair close to the candle for the requisite light. After registering the time, I looked out for a few minutes with the naked eye over the landscape, north and south. The north was clear, and the line of horizon could be distinctly seen. The Sun, covered by the Moon, looking like a blue patch in the sky, had now the corona very symmetrically formed around it; but the Moon appeared to my unassisted eye to be not very round or smooth at its edge,—more as if one had rudely cut out with a knife on a board a circular disc of card,—the edges somewhat jagged and irregular in outline.

"The corona itself was perfectly concentric and radiating, some of the rays appearing in some parts of the circumference a *little* longer than in others; but the inequality was not great. I am unable to say whether the corona when *first* found was at all eccentric, for, as it is evident that any one observing with a telescope up to the moment of obscuration must have time to take off the dark glass before the corona can be seen, and as I had also to note the *time*, the centres of the Sun and Moon must have been pretty closely approximating before I again applied the eye to the telescope. It was indeed a great exercise of self-denial to spare the time from the exciting phenomena, which was necessary for accurately recording the duration of total darkness; but being inclined to think such record would be disregarded by many observers, I took my resolution to secure it."

The writer then proceeds to say that Venus was the only object visible to the naked eye. The corona he describes as "brilliant," and he considers that it afforded, speaking roughly, as much light as the Moon usually does when at its full.

"I had intended to direct my attention pointedly to the detection of the 'Red Flames,' which I had heard described as but faint phenomena. My surprise and astonishment may therefore be well imagined when the view presented itself instantly to my eye as I am about to describe, or rather to attempt to give a notion of.

[b] *Sol. Syst.*, p. 71.

"In the middle of the field was the body of the Moon, rendered visible enough by the light of the corona around, attended by the apparent projections from behind the Moon of which I have attempted to sketch the positions. The effect upon my own mind of the awful grandeur of the spectacle I feel I cannot fully communicate. The prominences were of the most brilliant lake colour,—a splendid pink, quite defined and hard. They appeared to me to be not quiescent; but the Moon passing over them, and therefore exhibiting them in different phase, might convey an idea of motion. They are evidently to my senses belonging to the Sun and not at all to the Moon; for, especially on the western side of the Sun, I observed that the Moon passed over them, revealing successive portions of them as it advanced. In conformity with this observation also, I observed only the summit of *one*, on the eastern side, though my friends observing in adjoining rooms, had seen at least two: the time occupied by my noticing the time and observing with the naked eye not having allowed me to repair again to the telescope until the Moon had covered one, and three-fourths of the other. The point of the Sun's limit where the principal 'flame' appeared was (I judged) a few degrees south of the place where the cluster of spots was situated, and the flame which I observed on the eastern limb was almost exactly where the eastern spot was situated. As, however, some prominences appeared adjacent to parts of the Sun's limit not usually traversed by spots, the attempt to trace a connexion fails. The first burst of light from the emergent Sun was exactly in the place of the chief western flame, which it instantly extinguished . . . . . From the varying lengths of the red flames it is difficult to give an accurate estimation of their magnitude; but the extreme length of the largest, on the western limb, may have been about $2\frac{1}{2}'$. This estimation is rather rude, as I was so absorbed in contemplating their general phenomena that I had not time for exact measurement[c]."

[c] *Mem.* R.A.S., vol. xxi. p. 47. 1853.

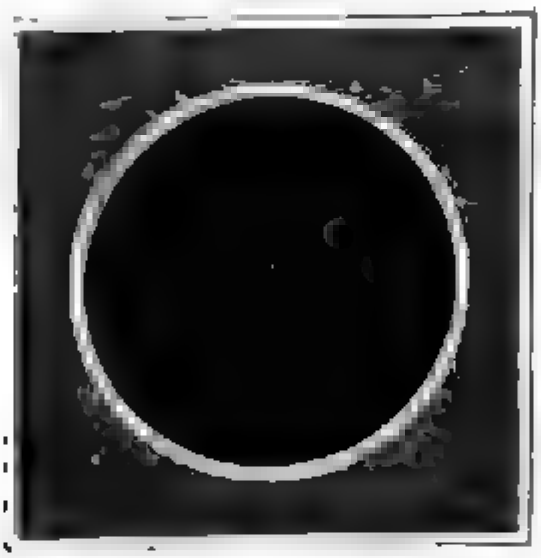
CHAPTER IV.

THE ANNULAR ECLIPSE OF THE SUN OF MARCH 14–15, 1858.

Summary of observations in England.

Of the different eclipses which have from time to time been visible in England, few have attracted such interest and attention among all classes of society as that of March 14–15, 1858. Though bad weather in most cases interrupted or altogether prevented observations, yet many instructive features were noticed.

Fig. 83.



Eclipse of the Sun, March 14–15, 1858: The Annulus.

The line of central and annular eclipse passed across England from Lyme Regis, in Dorsetshire, to the Wash, between Lincolnshire and Norfolk, traversing portions of the counties of Somersetshire, Wiltshire, Berkshire, Oxfordshire, and Northamptonshire. The following summary of the observations made, drawn up by Mr. Glaisher, will be read with interest:—

"From returns received between Braemar and the Channel Islands, from 30 to 40 in number, it is shewn that the depression of temperature during the eclipse was about 4½° at stations north of the line, and nearly 3° at stations on and south of the line of central eclipse; that at places where the usual diurnal increase had taken place in the morning the depression of temperature during the eclipse was greater:

and that at places where such increase had not taken place it was less than the above numbers. Also that at places where the sky was uniformly cloudy during the day the decrease in the readings of a black bulb thermometer was less than 12°, while at places where the sky was partially clear the depression was from 17° to 19°, and that, what temperature soever the black bulb thermometer indicated in the morning, it fell during the eclipse to that of the temperature of the air at all places.

"The humidity of the air was such that at places north of the line the wet bulb thermometer read 2·6° less; and on and near the line the depression was 3·2°, and south of it was 3·7° below the adjacent dry bulb thermometer.

"At some places the humidity of the air increased at the time of the greatest eclipse, but this was far from being universal.

"The sky was partially clear at some places on the east and south coasts, in the Channel Islands and north of Scotland, and it was for the most part overcast elsewhere. Near the southern extremity of the central line the sky was partially clear, and at its northern extremity near Peterborough the clouds were broken; at most intermediate places the sky was wholly overcast. The complete ring was seen at Charmouth, and neighbourhood near Lyme Regis, and at Peterborough, but, so far as I can learn, at no other places. My own station was on the calculated line of central eclipse, near Oundle, in Northamptonshire, and here I saw the Moon and Sun's apparent upper limb coincident, or very nearly so, and therefore that I was situated on or very near the northern limit of annularity, but distant from the centre line by 3 or 4 miles.

"It is very much to be regretted that the unfavourable weather precluded the witnessing the very beautiful attendant phenomena upon large solar eclipses. The time of year was unfavourable to all optical effects—whether of light and shade or colour, independently of the particular character of the day, which was more fatal still to their exhibition, for even where the Sun was visible their presence was only feebly indicated at a few parts of the country.

"At Oundle the weather for some time previous to the commencement of the eclipse was raw and ungenial for the time of year. The wind was gusty and the sky overcast, chiefly with cirro-stratus, and dark scud hurrying past the Sun's place from the north-west, the clouds occasionally giving way and allowing the Sun to be visible by glimpses. Shortly after 1 o'clock the sky became uniformly overcast, and a small steady rain set in for a considerable time.

"It was long before any sensible diminution of light took place. At $12^h\ 39^m$ a gloom was for the first time perceptible to the north, and the crescent of the Sun shone out with a bright white light between breaks. At $0^h\ 43^m$ the gloom was general, excepting around the Sun, which appeared the centre of a circle of light, and illuminated with fine effect some bold irregular masses of cumulus in its vicinity. At $0^h\ 45^m$ the gloom increased, slight rain fell, and the wind rose, birds were heard chirping and calling. At $0^h\ 53^m$ a severe storm might have been supposed impending, and numerous birds were flying homewards. The deepening of the gloom was gradual but very slow, and between 1^h and $1^h\ 1^m$ was at its greatest intensity; but even at this time the obscurity was not sufficient to require that any employment should be suspended. Messrs. Adams and Symons, situated five feet from a shed in an adjoining brick-field, spoke of the gloom as very intense for a period of 10 seconds, and sufficient to render it difficult to take the readings of the thermometer. A body of rooks rose from the ground at this moment and flew homewards; a flock of

starlings rose together, and various small birds flew wildly about; a hare was seen to run across a neighbouring field, as though it were daybreak; straw rustled, and the silence was peculiar and intense. The darkness and lull was that of an approaching thunder-storm. Directly after the greatest intensity the gloom was sensibly and instantaneously diminished, and the day was speedily restored to its ordinary appearance.

"After 0^h 50^m the lark ceased to rise, and did not sing; at 1^h 10^m it rose again. The collected information tends to shew that birds and animals, but particularly the former, were affected in some degree in most places; and that it is probable to suppose the gloom was referred by them to the approach of evening, and this not so much from the fact of the gloom as from the manner of its approach, without the accompanying signs of atmospheric disturbance which usher in a storm, and to which birds and animals are keenly sensitive.

"All over the country rooks seem to have returned to their rookeries during the greatest obscuration; starlings were seen in many places taking flight, whole flocks of them together. At Oxford Dr. Collingwood remarked that a thrush commenced its evening song. At Grantham pigeons returned to their cote. At Ventnor Dr. Martin notes the fact that a fish confined in an aquarium, and ordinarily visible at evening only, was in full activity about the time of the greatest gloom. In Greenwich Park the birds were hushed and flew low from bush to bush, and at nearly all places the song of many birds was suspended during the darkness. At Campden Hill it was observed that the crocus closed about the same time, and at Teignmouth that its colour changed to that of the pink hepatica.

"The darkness was not sufficient at any place to prevent moderate-sized print being read at any convenient distance from the eye out of doors, but a difficulty was sometimes experienced in reading the instruments. At Grantham the darkness is described to have been about equal to the usual amount of light an hour before sunrise; near Oxford as about equal to that just after sunset on a cloudy day. The general impression communicated was that of an approaching thunder-storm. The sudden clearing up of the gloom after the greatest phase was likened by more than one observer to the gradual, but somewhat rapid withdrawal of a curtain from the window of a darkened room. The darkness is described to have been generally attended by a sensation of chilliness and moisture in the air. At Oxford the clouds surrounding the Sun were beautifully tinted with red, which merged into purple as the obscuration increased. At Grantham as the eclipse progressed the light became of a decided grey cast, similar to that of early morning, but at the time of the greatest gloom it had a strong yellow tinge. At Teignmouth the diminution of light was very great; the sombre tints of the clouds became much deepened, and the remaining light thrown over the landscape was lurid and unnatural. At Greenwich the appearance of the landscape changed from a dull white to a leaden, and then to a slate-coloured hue; and as the darkness increased it had much the appearance of a November fog closing in on all sides. At Wakefield the tints of the clouds changed from the grey slate colour of clouds in a storm, and became of a purple hue. At Oundle, my own station, the clouds were one uniform leaden grey or slate colour, and quite in accordance with the general character of the day, nor could I perceive that the clouds appeared lower, or, in fact, that there was any very noticeable departure from the gloom we constantly experience during dull winter weather. Throughout the eclipse it occurred to me that the illuminating power of the Sun was much more than might have been supposed commensurate with the unobscured portion of the

disc. When casual breaks permitted it to be visible the illuminated crescent up to the time of the greatest phase emitted beams of considerable brilliancy, which marked out a luminous track in the gloom, and were clearly and well defined in extent and figure. As the eclipse proceeded a decided change was to be observed in the colour of the Sun itself, which became of a pure silvery brightness, like that of Venus after inferior conjunction with the Sun. The absence of all colour in the light was remarkable, and at the time when the annulus was nearly formed it appeared like a line of silver wire. The departure from the usual amount of light we are accustomed to receive on an ordinarily dull day during the greater part of the eclipse was so inconsiderable, that we might infer approximately the real amount of Sun our average daylight under a cloudy sky is equivalent to.

"As a photometric test during the eclipse, strips of photographic paper were exposed for equal intervals of time every 5 minutes. The result was a scale of tints which exhibited clearly the diminishing intensity of the light up to the period of greatest obscuration, and the rapid increase beyond. The range of tints is low, owing to the cloudy state of the sky, but this does not interfere with the proportionate depths of tint; the time of greatest darkness is distinctly shewn by the very feeble discoloration of the paper. The instruments used at Oundle were made specially for those observations, and were of a very delicate and accurate construction; the meteorological observations were made by Messrs. Adams and Symons.

"In conclusion, I beg sincerely to thank those gentlemen whose returns have supplied the data for this investigation, of which we may say, literally as well as figuratively, that it exhibits only the faint outline of facts dimly visible through a screen of clouds. I think, however, it is reasonable to infer that the great paucity of effects and general phenomena witnessed even in places where the Sun was visible, is due to the conditions of the atmosphere, attributable alike to climate, time of year, and unfavourable weather, and should by no means lessen our confidence in previous accounts of the grandeur and beauty of the attendant phenomena upon solar eclipses. Optical phenomena, we all know, are dependent upon the medium through which we view them for the nature and power of the effects produced."

CHAPTER V.

THE TOTAL ECLIPSE OF THE SUN OF JULY 18, 1860.

Extracts from the observations of the Astronomer Royal.—Observations of the Red Flames by Bruhns.—Meteorological observations by Lowe.

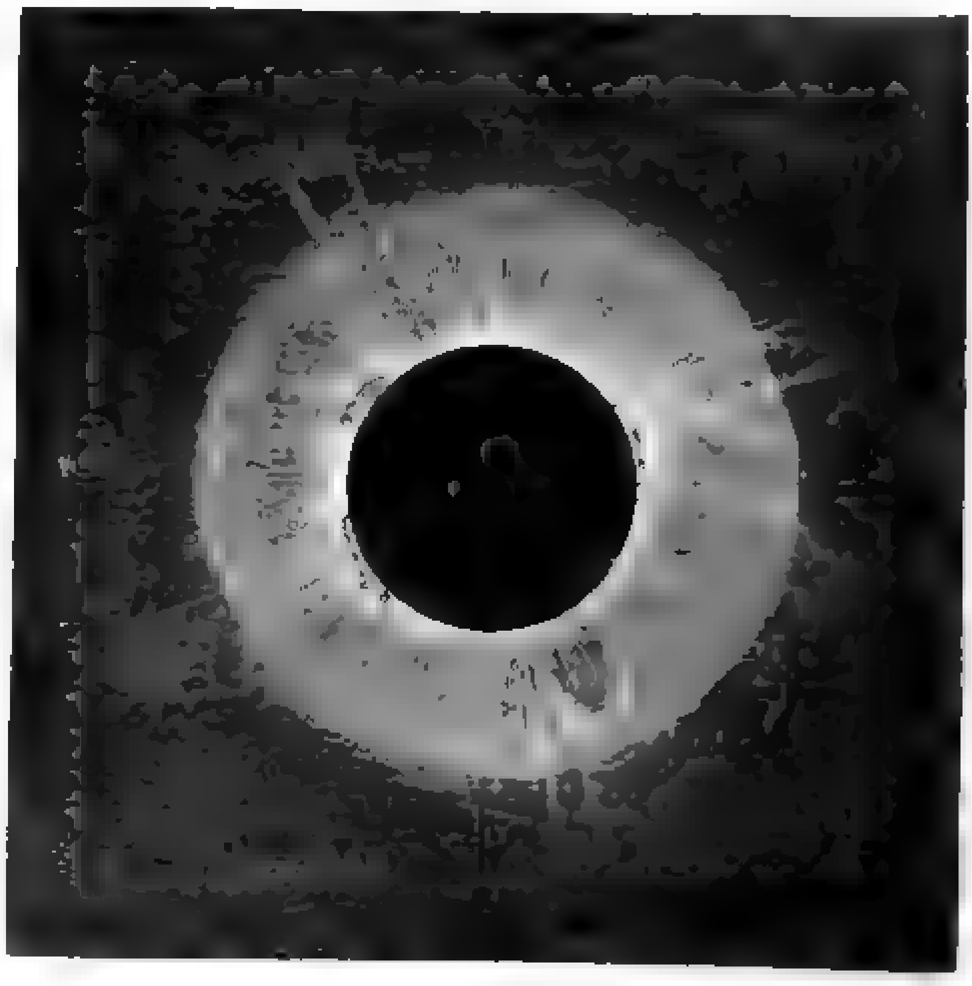
THE total eclipse of July 18, 1860, presented some noticeable features: it owed its interest to the agreeable circumstances connected with it [a], and its importance to the very extensive observations which were made by many astronomers in Europe, Africa, and America.

Sir G. B. Airy stationed himself at the village of Pobes, in the North of Spain. From his memoir [b] I make the following extracts:—

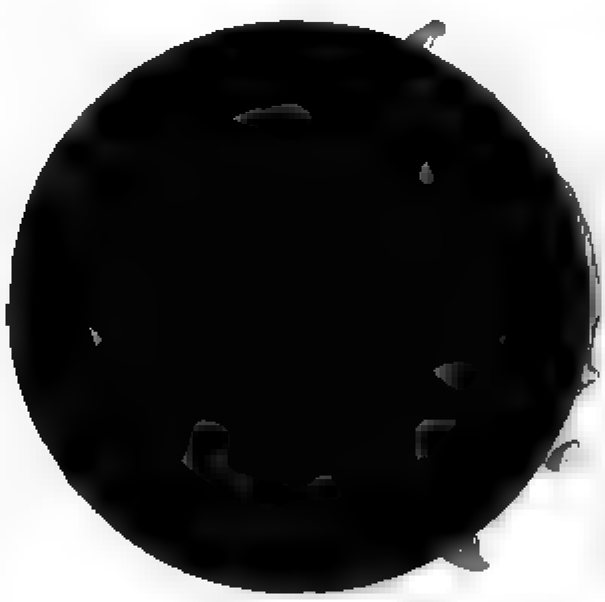
"On the progress of the eclipse I have nothing to remark, except that I thought the singular darkening of the landscape, whose character is peculiar to an eclipse, to be sadder than usual. The cause of this peculiar character I conceive to be the diminution of light in the higher strata of the air. When the Sun is heavily clouded, still the upper atmosphere is brilliantly illuminated, and the diffused light which comes from it is agreeable to the eye. But when the Sun is partially eclipsed, the illumination of the atmosphere for many miles round is also diminished, and the eye is oppressed by the absence of the light which usually comes from it.

"I had a wax candle lighted in a lantern, as I have had at preceding total eclipses. Correcting the appreciations of my eye by reference to this, I found that the darkness of the approaching totality was much less striking than in the eclipses of 1842 and 1851. In my anxiety to lose nothing at the telescope I did not see the approach of the dark shadow through the air; but, from what I afterwards saw of its retreat, I am sure it must have been very awful."

[a] It is to the *Himalaya* expedition to Spain that allusion is here made.
[b] *Month. Not.*, vol. xxi. p. 9. Nov. 1860.



(*Feilitzsch.*)



Bruhns.)

(*Bruhns.*)

THE TOTAL ECLIPSE OF THE SUN OF JULY 18, 1860.

TELESCOPIC VIEWS OF THE CORONA AND RED FLAMES.

After describing the Red Flames, he says:—

"I may take this opportunity of stating, that the colour of these appearances was not identical with that which I saw in 1842 and 1851. The *quality* of the colour was precisely the same (full blush-red, or nearly lake), but it was diluted with white, and more diluted at the roots of the prominences close to the Moon's limb than in the most elevated points.

"About the middle of the totality I ceased for awhile my measures, in order to view the prospect with the naked eye. The general light appeared to me much greater than in the eclipses of 1842 and 1851 (one cloudy, the other hazy), perhaps 10 times as great; I believe I could have read a chronometer at the distance of 12 inches; nevertheless, it was not easy to walk where the ground was in the least uneven, and much attention to the footing was necessary. The outlines of the mountains were clear, but all distances were totally lost; they were in fact an undivided mass of black to within a small distance of the spectator. Above these, to the height perhaps of 6° or 8°, and especially remarkable on the north side, was a brilliant yellow or orange sky, without any trace of the lovely blush which I saw in 1851. Higher still, the sky was moderately dark, but not so dark as in former eclipses. The corona gave a considerable body, but I did not remark either by eye-view or by telescope-view anything annular in its structure; it appeared to me to resemble, with some irregularities (as I stated in 1851), the ornament round a compass card. But the thing which struck me most was the great brilliancy of Jupiter and Procyon so near the Sun. It was impossible that they could have been seen at all, except under the circumstance of total absence of illumination on that part of the atmosphere through which the light passed. I returned to my measures, but I was soon surprised by the appearance of the scarlet sierra, announcing the approach of the Sun's limb. It disappointed me, for I had reckoned on a much longer time. All our party who were aware of the predicted duration fully believed that it must have been very erroneous. How the time passed I cannot tell. The Sun at length appeared, extinguishing the sierra, but the prominence and cloud remained visible, and my last measures were taken after reappearance. The prominences, &c. were then rapidly fading, and I quitted the telescope, not without the feeling that I had not done all that I had intended or hoped to do."

The Red Flames were seen, and described by many of the observers; the account given by M. Bruhns is the most complete[c]. He says:—

"Just before the totality, there was visible, on the western border of the Moon, only one protuberance and the corona; but as the last rays of the Sun disappeared, more protuberances started out on the eastern side, and the corona shone forth with an intense white light, so lustrous in fact as to dim the protuberances. I remarked that I saw them better when a clear red glass was held before my eye.

"During the totality I sketched 4 drawings, and also measured off the position-angles of the different protuberances, counting round the circle from the north point through the east, &c.

"The figure marked [Fig. 85, Pl. XIII] was drawn during the first minute of the totality. The first protuberance is the one already mentioned; its position-angle

[c] *Ast. Nach.*, vol. liv. No. 1292. Jan. 22, 1861.

was 35°, the length of its base 1½′ or 2′, and its height about the same. The summit was somewhat curved, of an intense rose colour, but a little paler at the apex.

"The second protuberance, situated at 60°, was completely separated from the Moon, there being between them an interval of ½′. For part of its extent it was parallel to the Moon's border, it then deviated from it, and ended in a point. Its length was 1½′ or 2′, its height about ½′, and of a rose colour.

"The third protuberance, having a position-angle of 75°, resembled a mountain, and had a base of 1½′, and a height of fully ½′. Extending onwards for 50° from this protuberance was a narrow fringe, first of a pale red, but a few seconds afterwards it came over a splendid rose colour, and of a height of about ½′, which soon narrowed as the Moon passed over it, until at length it was quite covered.

"A fourth protuberance existed at 155°; its base was not more than ¾′, but the height was as much as 1½′. It had a hooked form with the curve trending northwards, and likewise of a rose colour.

"During no part of the totality were there any protuberances visible in the southern part of the Sun's disc.

"In the second minute the above-described protuberances became gradually smaller; with the exception of the first, which retained its magnitude and figure almost unchanged. The above-described unattached protuberance [No. 2] was reached by the Moon, and became gradually covered. By the end of the second minute the fringe was entirely covered, and at this juncture, on turning to examine the western border of the Moon, I perceived several protuberances, not previously visible.

"The protuberance situated at 260°, which I will call No. 5, had, at the beginning of the second [third?] minute, only a base of ½′, and about the same height, the colour being rose.

"Between 270° and 300° extended a second streak about ½′ in height.

"A sixth protuberance was visible at 310°, having a base of 2′, and a height of ¾′.

"Lastly, I found at 340° a seventh protuberance, having a base of 1′, and a height of ¾′, and of a rose colour, like all the preceding.

"On directing my attention to the first protuberance (the one at 35°), I fancied it had grown considerably larger. The sharp edge, first seen, had disappeared, and for a height of 3′ or 4′ flaming rays could be discerned, the colour (at the base a bright rose) was, at the top, hardly perceptible, but seemed to fade off and become merged in the corona.

"After I had observed these for about half a minute, without perceiving any alteration, I quitted the telescope to observe the corona and the sky for a short time with the naked eye. The black-looking Moon was surrounded by a crown of clear light of unequal breadth. Below [S.] it was considerably greater than above [N.]. I estimated that in the former case it was ⅜°, in the latter about ¼°, and the general appearance of the thing gave me the idea that the Moon was eccentrically placed in the corona.

"The general form of the corona appeared circular, but on the eastern side a long ray shot out to a distance of about 1°; the breadth of its base was 3′, but it tapered down to about 1½′. During the 10 seconds that my attention was directed to it, neither the direction nor the length of the ray altered; its light was considerably feebler than that of the corona, which was of a glowing white, and seemed to coruscate or twinkle.

"With the naked eye I easily saw Venus and Jupiter, the former being much

brighter than the latter. Although I knew whereabouts Procyon, Castor, Pollux, Mercury, and Saturn were, yet in the few seconds available for seeking for them I failed to find them.

"My assistant, M. Auerbach, who observed the corona, and searched for the stars during a longer period than I did, noticed in the south-western quadrant a curved ray about $\frac{1}{10}°$ in length, which I in my hurry probably overlooked. He also saw Pollux, and another person saw Castor; but, as far as I am aware, no more than the above 4 objects were seen by any person in Tarragona.

"Towards the end of the 3rd minute of the totality, I again looked through the telescope, and made the drawing [Fig. 86, Pl. XIII]. The western protuberances had altered considerably since the 2nd minute; the one at 35° had regained its original form and size, the flaming rays, previously spoken of, having disappeared. The protuberance in 340° had become much larger, the length of its base being now about 2′, and the height $1\frac{1}{2}'$. The red streak extending from 270° to 300° had prolonged itself so as to take in the protuberance at 310° [No. 6], and had altogether now a length of 50°, its height having also become augmented from $\frac{1}{4}'$ to 1′, and its colour being an intense rose. The protuberance at 260° [No. 5] was now separated by about $\frac{1}{4}'$ from the Moon, its breadth being nearly 1′, and its height $\frac{1}{2}'$. Finally, at 240° a new and small protuberance had started into view, its base and height were both about $\frac{1}{2}'$, and rose-coloured.

"As the end of the totality advanced so the protuberances became less distinct, the colour became brighter, and immediately after the 3rd minute of totality the protuberances at 240° and 260° disappeared; the fringe extending itself to a length of more than 90°, its height being $1\frac{1}{2}'$, and embraced all the protuberances up to an angle of 35°. On the first appearance of the solar rays all suddenly vanished, with the exception of the first protuberance, which for some time afterwards remained visible in the thin red glass."

Meteorology was not unrepresented in Spain, for Mr. E. J. Lowe, at Fuente del Mar, near Santander, with 2 assistants, during a period of 5 hours, made upwards of 4000 observations. The following is an abstract of Mr. Lowe's results, in his own words:—

"Commencing with underground temperature, a thermometer placed 6 inches below the surface of the ground ranged between 67·9° and 70·7°, *i.e.* 2·8°; at this depth the eclipse was not sensibly felt, whereas other thermometers, placed 4 inches, 2 inches, 1 inch, and $\frac{1}{2}$ an inch below the surface, all exhibited in a very marked manner the effect of the eclipse. On the grass the temperature fell to 64° at $3^h\ 5^m$; at $\frac{1}{2}$ inch below the surface, to 69° at $3^h\ 15^m$; at 1 inch deep, to 69·5° at $3^h\ 25^m$; at 2 inches, to 71° at $3^h\ 55^m$; at 4 inches, to 70·7° at $4^h\ 30^m$ P.M.

"The temperature on the grass was 77·5° at noon, rising to 91·7° at $1^h\ 50^m$, and then falling till $3^h\ 5^m$, and again rising to 85° at $4^h\ 10^m$, giving a range of 27·7°. At half an inch below the surface of the ground the temperature rose till $1^h\ 55^m$ P.M., when it was 78·5°, and then gradually fell to 69°, rising again to 74·7° at $4^h\ 30^m$ P.M., the range being 9·5°. At 1 inch below the surface the temperature rose till $1^h\ 55^m$ to 76·2°, fell till $3^h\ 25^m$ to 69·5°, and rose till $4^h\ 55^m$ to 74·7°, the range being 6·7°. At 2 inches below the surface the temperature rose till $2^h\ 5^m$ to 74·4°, then fell till $3^h\ 55^m$ to 71·0°, and afterwards rose till $4^h\ 55^m$ to 73·7°, the range being 3·4°; and at

4 inches below the surface the temperature rose till $2^h\ 50^m$ to $73°$, then fell till $4^h\ 30^m$ to $70·7°$, and again rose till 6^h P.M. to $73·2°$, the range being $2·5°$.

"The greatest cold on the ground occurred between 3^h and $3^h\ 5^m$ P.M.; ditto, $\frac{1}{2}$ an inch below surface, $3^h\ 10^m$ and $3^h\ 15^m$ P.M.; ditto, 1 inch, $3^h\ 20^m$ and $3^h\ 25^m$ P.M.; ditto, 2 inches, $3^h\ 50^m$ and $3^h\ 55^m$ P.M.; ditto, 4 inches, $4^h\ 25^m$ and $4^h\ 30^m$ P.M.

TABLE OF TEMPERATURES.

	Commencement of Eclipse.	Middle of Eclipse.	End of Eclipse.	Range during Eclipse.
	°	°	°	°
Of a blackened ball on grass	104·0	65·5	94·0	38·5
Of a blackened ball in vacuo	131·0	66·0	104·0	65·0
In sunshine at 2 feet above ground ..	75·5	63·6	70·0	11·9
In sunshine 2 feet (wet bulb)	69·5	59·3	65·5	10·2
Diff. between dry and wet bulb at 2 feet	6·0	4·4	4·5	1·6
In shade at 4 feet	70·0	64·7	71·0	6·3
In shade at 4 feet (wet bulb)	62·5	59·7	63·5	3·8
In shade at 3 feet	70·2	64·2	70·7	6·5
In shade at 2 feet	68·5	62·5	68·5	6·0
In shade at 1 foot	70·7	64·5	70·2	5·7

"The barometer rose from $1^h\ 40^m$ till $2^h\ 10^m$ 0·002 inch, then fell till $3^h\ 5^m$ 0·0017 inch, and rose till end of eclipse, 0·009 inch.

"Intensity of photographic light, from salted papers conveyed, sensilised, in Marion's dark box, exposed for 10 seconds (with a scale of from 0 to 5°), at the commencement of the eclipse, $4\frac{1}{2}°$ becoming 4° at $2^h\ 5^m$, 3° at $2^h\ 15^m$, 2° at $2^h\ 25^m$, 1° at $2^h\ 40^m$, $\frac{3}{4}°$ at $2^h\ 50^m$, 1° at $2^h\ 55^m$ (clear about Sun), $\frac{1}{4}°$ at 3^h, 1° at $3^h\ 5^m$, 2° at $3^h\ 25^m$, $2\frac{1}{2}°$ at $3^h\ 40^m$, 3° at $3^h\ 50^m$, and 4° at 4^h. During totality a paper exposed for 1 minute gave $\frac{3}{4}$.

"The wind was N.W. and N.N.W. till $4^h\ 20^m$ then W.S.W., being S.W. at $4^h\ 25^m$, and South at $4^h\ 45^m$. The wind was brisk at the commencement of the eclipse, quite a calm during totality, and a gentle breeze afterwards. The distant prospect was very clear, except during totality, when the mountains disappeared, and only near objects were visible.

"The clouds, which were chiefly cumuli, diminished in amount till $1^h\ 50^m$, when only $\frac{4}{10}$ of the sky was overcast, then increased till $2^h\ 35^m$ with much cloud till $3^h\ 55^m$, then again diminished to $\frac{6}{10}$ at the termination of the eclipse, the range being $\frac{5·5}{10}$ of the whole sky. Towards totality some of the cumuli became scud, which lasted from $2^h\ 5^m$ to $3^h\ 10^m$, giving the strongest impression that the change was due to the eclipse.

"The morning was fine, and from $12^h\ 45^m$ P.M. sunshine; at $1^h\ 25^m$ much open sky about the zenith; at $2^h\ 15^m$ a blackness about W. horizon, and slightly so in N. and S.; at $2^h\ 30^m$ the hills dark, and the blue sky in N. and E. very pale in colour; at $2^h\ 35^m$, hills dark, with a blue haze among the more distant mountains; at

2^h 40^m, horizon due W. pink; at 2^h 45^m, clear sky, in N. pink; at 2^h 52^m, splendid pink in W. horizon, warm purple in summits of mountains in S., clear sky, in N. deep lilac, and in E. very pale blue; at 2^h 57^m, rapid change, the clear sky in N. deep marine blue with a red line.

"Before totality commenced, the colours in the sky and in the hills were magnificent beyond all description; the clear sky in N. assumed a deep indigo colour, while in the W. the horizon was pitch black (like night). In the E. the clear sky was very pale blue, with orange and red, like sunrise, and the hills in S. were very red; on the shadow sweeping across, the deep blue in N. changed like magic to pale sunrise tints of orange and red, while the sunrise appearance in E. had changed to indigo. The colours increased in brilliancy near the horizon, overhead the sky was [of a] leaden [hue]. Some white houses at a little distance were brought nearer, and assumed a warm yellow tint; the darkness was great; thermometers could not be read. The countenances of men were of a livid pink. The Spaniards lay down, and their children screamed with fear; fowls hastened to roost, ducks clustered together, pigeons dashed against the sides of the houses, flowers closed (*Hibiscus Africanus* as early as 2^h 5^m); at 2^h 52^m cocks began to crow (ceasing at 2^h 57^m, and recommencing at 3^h 5^m). As darkness came on, many butterflies, which were seen about, flew as if drunk, and at last disappeared; the air became very humid, so much so that the grass felt to one of the observers as if recently rained upon. So many facts have been noted and recorded that it is impossible to do more than give a brief statement of the leading features."

The general result of the observations of the eclipse of 1860 was to shew conclusively that the Red Flames in solar eclipses belong not to the Moon but to the Sun.

An interesting and valuable memoir on this eclipse was presented to the Royal Society by Mr. Warren De La Rue, and published in vol. clii. of the *Philosophical Transactions*.

CHAPTER VI.

RECENT TOTAL ECLIPSES OF THE SUN.

Eclipse of August 18, 1868.—Observations by Col. Tennant and M. Janssen at Guntoor.—Summary of results.—Observations of Governor J. P. Hennessy and Capt. Reed, R.N.—Eclipse of August 7, 1869.—Observations in America by Prof. Morton and others.—Summary of results.—Eclipse of December 22, 1870.—English expedition in H.M.S. Urgent to Spain.—Observations in Spain and Sicily.—Summary of results.—Rifts seen in the Corona.—Sir J. Herschel's interpretation of the observations.—Characteristics of the Corona.—Eclipse of December 11, 1871.—Observed in India.—De La Rue's review of the progress of knowledge respecting Eclipse phenomena.—Eclipse of April 16, 1874.—Observations by Stone and others in South Africa.—Contraction of the Corona in the direction of the Sun's axis.—Concluding summary as to the Physical Constitution of the Sun.—Enumeration of its several envelopes.

THE eclipse of the Sun of July 18, 1860, described in the last chapter, may be said to mark a turning-point in the history of eclipse phenomena. It was the first in which photography played a conspicuous part, and the experience acquired by the numerous observers who went to Spain, paved the way for the great photographic and other successes which marked subsequent eclipse expeditions.

The reader who has studied what has been stated in the earlier chapters of this book, respecting the usual accompaniments of eclipses of the Sun, will already have acquired a sufficiently complete general insight into the subject, and therefore in the present chapter his attention will be mainly invited to new points.

The eclipses which will be grouped together here are the following[a]:—August 18, 1868; August 7, 1869; December 22, 1870; December 11, 1871; and April 16, 1874.

[a] A very good general summary of the eclipse observations made in 1868, 1869, and 1870 (accompanied by numerous illustrations) will be found in the Eng-

To observe the eclipse of 1868, several expeditions were dispatched from Europe to the East Indies. The most important of these was that which under the command of Major Tennant, R. E., went to Guntoor (Lat. 16° 17′ 27″ N., Long. $5^h\ 21^m\ 48^s$ E.); but important service was rendered to science by a French observer, M. Janssen, who, accompanied by his wife, stationed himself at Guntoor. Another French party, under M. Stéphan, went to Siam, and a German party to Aden. This last-named contingent included MM. Weiss, Oppolzer, and Thiele, all experienced astronomers. A Spanish party, headed by M. Fauro, a priest of Manilla, went to Mantawalu-kiki, in the Gulf of Gorontolo, Celebes. Nor should the labours of Mr. Pogson at Madras and of Governor J. P. Hennessy in Borneo be forgotten.

Major Tennant's arrangements were framed with the object of (1) investigating by the aid of a spectroscope the corona and red flames (the latter now universally called the "Solar prominences"), as regards the source of their light; (2) examining the light of the corona and prominences as regards the polarisation thereof, and (3) obtaining photographs during the totality. By a due subdivision of labour amongst the different members of the expedition this programme was carried to a successful conclusion. Neglecting certain optical effects, common to every total eclipse of the Sun, and sufficiently described already in connection with previous eclipses, I proceed to note briefly, in something like Major Tennant's own words, his deductions as to the new results flowing from the labours of himself and his colleagues [b].

The corona is to be deemed an atmosphere of the Sun, not self-luminous but shining by reflected light. This was proved both by the spectroscope and the polariscope.

During the continuance of the totality, there was seen on the North side of the Sun, an enormous horn of light, the apex of which was calculated to be about 90,000 miles distant from the Sun's limb. This object presented in a striking degree indications

lish edition of Schellen's *Die Spectralanalyse.* The information relating to the 1870 eclipse is exclusively from English sources drawn upon by the translators. But the most exhaustive account by far is that furnished in *Mem.* R.A.S., vol. xli. 1876. This volume is a magnificent compilation of Eclipse facts. For it science is mainly indebted to Mr. A. C. Ranyard.

[b] *Memoirs* R.A.S., vol. xxxvii. p. 1. 1869.

of a spiral structure, and was presumed to consist of incandescent vapours of hydrogen, sodium, and magnesium.

Capt. Branfill observed that the corona was strongly polarised everywhere in a plane passing through the Sun's centre.

The general phenomena of the total phase are thus described by Mr. Hennessy [c]:—

"Ten minutes before the total eclipse there seemed to be a luminous crescent reflected upon the dark body of the Moon. In another minute a long beam of light, pale and quite straight, the rays diverging at a small angle, shot out from the Westerly corner of the Sun's crescent. At the same time Mr. Ellis noticed a corresponding dark band, or shadow, shooting down from the East corner of the crescent. At this time the sea assumed a darker aspect, and a well-defined green band was seen distinctly around the horizon. The temperature had fallen, and the wind had slightly freshened. The darkness then came on with great rapidity. The sensation was as if a thunderstorm was about to break, and one was startled on looking up to see not a single cloud overhead. The birds, after flying very low, disappeared altogether. The dragon-flies and butterflies disappeared, and the large drone-like flies all collected on the ceiling of the tent, and remained at rest. The crickets and Cicadæ in the jungle began to sound, and some birds, not visible, also began to twitter in the jungle. The sea grew darker, and immediately before the total obscuration the horizon could not be seen. The line of round white clouds that lay near the horizon changed their colour and aspect with great rapidity. As the obscuration took place, they all became of a dark purple, heavy looking, and with sharply defined edges; they then presented the appearance of clouds close to the horizon after sunset. It seemed as if the Sun had set at the four points of the horizon. The sky was of a dark leaden blue, and the trees looked almost black. The faces of the observers looked dark, but not pallid or unnatural. The moment of *maximum* darkness seemed to be immediately before the total obscuration; for a few seconds nothing could be seen except objects quite close to the observers. Suddenly there burst forth a luminous ring around the Moon. This ring was composed of a multitude of rays quite irregular in length and in direction; from the upper and lower parts they extended in bands to a distance more than twice the diameter of the Sun. Other bands appeared to fall towards one side, but in this there was no regularity, for bands near them fell away apparently towards the other side. When I called attention to this, Lieut. Ray said, 'Yes, I see them; they are like horses' tails;' and they certainly resembled masses of luminous hair in complete disorder. I have said these bands appeared to fall to one side; but I do not mean that they actually fell, or moved in any way, during the observation. If the atmosphere had not been perfectly clear, it is possible that the appearance they presented would lead to the supposition that they moved; but no optical delusion of the kind was possible under the circumstances. During the second when the Sun was disappearing, the edge of the luminous crescent became broken up into numerous points of light. The moment these were gone, the rays I have just mentioned shot forth, and, at the same time, we noticed the sudden appearance of the rose-coloured protuberances. The first of these was about $\frac{1}{4}$ of the Sun's diameter

[c] *Proc. Roy. Soc.*, vol. xvii. p. 84. 1868.

in length, and about $\frac{1}{24}$ of the Sun's diameter in breadth. It all appeared at the same instant, as if a veil had suddenly melted away from before it. It seemed to be a tower of rose-coloured clouds. The colour was most beautiful—more beautiful than any rose-colour I ever saw; indeed, I know of no natural object or colour to which it can be with justice compared. Though one has to describe it as rose-coloured, yet in truth it was very different from any colour or tint I ever saw before. This protuberance extended from the right of the upper limb, and was visible for 6 minutes. In 5 seconds after this was visible, a much broader and shorter protuberance appeared at the left side of the upper limb. This seemed to be composed of two united together. In colour and aspect it exactly resembled the long one. This second protuberance gradually sank down as the Sun continued to fall behind the Moon, and in 3 minutes it had disappeared altogether. A few seconds after it had sunk down there appeared at the lower corresponding limb (the right inferior corner) a similar protuberance which grew out as the eclipse proceeded. This also seemed to be a double protuberance, and in size and shape very much resembled the second one; that is, its breadth very much exceeded its height. In colour, however, this differed from either of the former ones. Its left edge was a bright blue, like a brilliant sapphire with light thrown upon it. Next to that was the so-called rose-colour, and, at the right corner, a sparkling ruby tint. This beautiful protuberance advanced at the same rate that the Sun had moved all along, when suddenly it seemed to spread towards the left until it ran around ¼ of the circle, making a long ridge of the rose-coloured masses. As this happened, the blue shade disappeared. In about 12 seconds the whole of this ridge vanished, and gave place to a rough edge of brilliant white light, and in another second the Sun had burst forth again. In the meantime the long rose-coloured protuberance on the upper right limb had remained visible; and though it seemed to be sinking into the Moon, it did not disappear altogether until the lower ridge had been formed, and had been visible for 2 seconds. This long protuberance was quite visible to the naked eye, but its colour could not be detected except through the telescope. To the naked eye it simply appeared as a little tower of white light, standing on the dark edge of the Moon. The lower protuberance appeared to the naked eye to be a notch of light in the dark edge of the Moon—not a protuberance, but an indentation. In shape the long protuberance resembled a goat's horn. . . . Though the darkness was by no means so great as I had expected, I was unable to mark the protuberances in my note-book without the aid of a lantern, which the sailors lit when the eclipse became total. Those who were looking out for stars counted 9 visible to the naked eye; one planet, Venus, was very brilliant. . . . On board the *Rifleman* the fowls and pigeons went to roost, but the cattle showed no signs of uneasiness; they were lying down at the time."

Captain Reed, R. N., remarked as follows respecting the corona:—

"The corona I should not describe as a ring, except in so far as concerned that portion of it immediately surrounding the Moon's limb. From this edge it burst forth in sharp, irregular-shaped masses, of exceedingly bright light, decreasing in brightness as the distance from the Moon increased, and finally resolving into numberless bright rays, the visible extremes of which were distant from two to three diameters of the Moon. The general appearance of the corona, as seen through my glass, struck me forcibly as resembling in form a Brunswick star; the bright light

near the Moon resembling the prominent portions immediately surrounding the centre, and the rays the more remote portions. I have heard the appearance described as representing the glory one sees around the heads of saints in old Italian pictures, and to my mind the general appearance could hardly be better described."

The total eclipse of August 7, 1869, was observed by several well-equipped parties in the United States. The American observations were carried out with great skill, and regardless of labour or expense, and resulted in a very complete series of excellent photographs[d]. One of these taken at Ottumwa represents the phenomenon of "Baily's Beads" and is, I believe, the only photographic record of this phenomenon extant. Professor Morton speaks of this as "simply the last glimpse of the Sun's edge cut by the peaks of the Lunar Mountains into irregular spots." The pictures taken during the partial phase all shew an increase of light on the Sun's surface, in contiguity with the Moon's limb, as was observed by De La Rue in 1860. Professor Morton was at first inclined to attribute this to the existence of a Lunar atmosphere; but subsequent experiments have led him to regard the cause as entirely chemical, and not corresponding to any celestial phenomenon. An analogous appearance is frequently to be seen in terrestrial photographs, and it is now generally agreed that the effect is a mere photographic one. Professor Pickering at Mount Pleasant noticed that while "the sky was strongly polarised all round close up to the corona, that object itself was not a source of polarised light." This observation is not in accord with the observations of other eclipses (especially 1842, 1851, 1860, and 1868), for it has always been found that the light of the corona was strongly polarised. Nor indeed do Pickering's observations in 1869 tally with his own conclusions arrived at in 1870 in Spain with similar instruments.

Much more important in every sense than either of the foregoing eclipses, was the eclipse of December 22, 1870. Being visible at some very accessible places in Spain, Sicily, and North Africa, several expeditions were dispatched to observe it, and eventually Her Britannic Majesty's Government placed at the disposal of

[d] *Report on Observations of the Total Eclipse of the Sun, Aug. 7, 1869.* Edited by Commodore B. F. Sands. 4to. Washington, 1869. *Month. Not.*, vol. xxx. p. 4 (Nov. 1869); p. 173 (May 1870); *Journal of the Franklin Institute*, 3rd ser., vol. lviii. pp. 200, 249, and 354 (Sept.–Nov. 1869).

English astronomers £2000 and a ship, the *Urgent,* for the conveyance of observers going to Spain and Africa; and the expenses of the party which travelled overland to Sicily were defrayed out of this grant. Besides the observing parties connected with the expeditions just named, a strong detachment of American astronomers, nearly all of them "Professors," came to Europe. France was only represented by M. Janssen, for the eclipse occurring towards the end of the Franco-German War, the French had other things to think about. It deserves notice that so great was M. Janssen's anxiety to observe the phenomenon, that he determined upon trying to escape from Paris in a balloon, and succeeded, carrying with him his instruments.

Unfortunately the weather was very unsatisfactory, especially in the North of Africa, where a cloudless sky had been confidently anticipated, and accordingly the successful photographs of Lord Lindsay's party at Cadiz and of the English party at Syracuse, constitute the chief direct results of the efforts made. The partial failure of the weather is the more to be regretted because the preparations made to observe the eclipse were unusually elaborate and costly, and the services of a particularly strong body of experienced observers had been secured. The general results, though less than had been expected, were undoubtedly of great importance, and constituted a clear advance in our knowledge of Solar physics.

Though attention was paid to other accompaniments of total eclipses of the Sun, and useful confirmatory evidence as to other matters was accumulated, yet the Sun's corona was in 1870 the one main object of attack, and photography, polariscopes, spectroscopes, and ordinary telescopes were all brought to bear on the elucidation of the question "What is the corona?" and important information available for answering the question was obtained. Although it is too much to say that the corona had been recognised to consist of two zones of light*—an inner and an outer one—yet various observers on previous occasions had noticed and recorded that differences of unknown character did

* As far back as 1842 use was made of the word "zone" for drawing a distinction between different portions of the corona, but the distinction seems not to have attracted much attention. Arago mentions it, but in unfavourable terms. (See the *Annuaire du Bureau de Longitudes* for 1846.)

exist in the interior and exterior portions of the corona. The eclipse observations of Dec. 12, 1870, clearly shew that the corona of that date was in some sense a compound ring of light, and this may be regarded as a fact both indisputable and universally recognised by astronomers. The features here alluded to are described by Lieut. A. B. Brown, R. A., one of Lord Lindsay's party at Cadiz. He says that there was a difference in the corona near the Sun:—

"It seemed to me distinct from the rest of the corona and to be irregular in outline, bulging out or extending much further from the Sun in some places, whereas in others it took the form of concentricity with the Sun; it had, moreover, the colour and appearance of pearl, with a bright phosphorescent tone about it, and was similar and dense throughout, whereas the rest of the corona had a faint violet colour, tinged in places with faint green and faint yellowish-red, and decreasing in luminosity as its distance from the Sun increased; moreover, it was jagged somewhat in outline, and had gaps in it (as seen in sketch), and very faint striations might be seen in it; the inner portion, as I have said, was quite different; and I should consider it an achromatic chromosphere surrounding the regular chromosphere, and separating it from the corona[f]."

The "gaps" spoken of in the foregoing extract must not be hastily passed over, for one of them in particular turned out to have been a notable characteristic of this eclipse[g]. It was a conspicuous feature in a photograph taken by Willard, one of the American observers at Cadiz, and likewise in a photograph taken by Brothers at Syracuse. What is implied in this identity of form in a feature seen at two places wide apart and under dissimilar circumstances is nowhere better expressed than in a letter of Sir J. Herschel's:—"Assuredly the decidedly marked notch or bay in both photographs (those taken at Cadiz and Syracuse) agreeing so perfectly in situation (marked so definitely by its occurrence just opposite the middle point between 2 unmistakable red prominences) is evidence not to be refused of its extra-atmospheric origin, and *almost* conclusive of its proximity to the solar globe[h]."

In giving utterance to this conclusion and in thus interpreting the observed facts, Sir J. Herschel may be taken to have been

[f] *Month. Not.*, vol. xxxi. p. 56 (Jan. 1871).

[g] I say this because I think it may be concluded that one of Lieut. Brown's "gaps" is identical with the "rift" commented on by other observers, but Lieut. Brown's account is given in such very bad English, that it taxes the capacity of the reader to understand it.

[h] *Month. Not.*, vol. xxxi. p. 169 (Mar. 1871).

a spokesman for astronomers generally, and it is now open to no question that the corona, whatever its precise nature may be, is assuredly an appendage of the Sun[1].

Estimates of the breadth of the inner corona varied somewhat. Photographs by Brothers and by Willard indicate a breadth of about 5′. The breadth of the corona as a whole, as seen in one of the photographs, appears to have been quite $1\frac{1}{2}°$.

As regards the shape of the corona—a comparison of the accounts seems to show that in 1870 it appeared very generally to be less compact and symmetrical than on former occasions. The Rev. S. J. Perry goes so far as to say that it was "approximately quadrilateral." Many observers of the corona noticed indications therein of a radial structure. As to its extension relative to the area of Sun-spot and Prominence developement we know but little, and I question whether our knowledge of the state of things subsisting in the photosphere and chromosphere of the Sun, is sufficiently advanced to justify our framing any theories respecting the contour of the corona, but this statement must be read in connection with Stone's observations in 1874, mentioned further on. And this remark of doubt applies also to the streamers seen in 1860 and in other eclipses, the existence of which is beyond question, but the origin of which is uncertain. As to all the points here discussed together in a very concise form, probably it will not be wide of the mark to say that important discoveries are dawning upon us, especially as it has been definitely established that there exists no intimate relationship between regions of special Sun-spot disturbance and regions of special Prominence-disturbance. That the coronal streamers have nothing to do with the Sun or corona itself seems incredible, despite the improbable theories to connect them with atmospheric causes.

We have seen that successive eclipses of the Sun up to 1870 materially increased our knowledge, and enlarged our ideas respecting various matters connected with the physical constitution of the Sun and its envelopes. The failure of the weather at so many stations in 1870, had the effect of robbing astronomy of a good deal of interesting knowledge which was all but within

[1] To avoid misconceptions it may be well to state that the solar origin of the corona was really rendered more or less certain long antecedent to 1870.

grasp. It is therefore a matter of congratulation that whilst the observations and experiences of 3 important eclipses were fresh in men's minds, a fourth important eclipse should occur under circumstances favourable to its careful observation.

The eclipse of December 12, 1871, was visible over a large and accessible tract of country in Southern India, Ceylon, and Australia, though in the last-named part of the world the weather failed. The observations made were as before photographic, spectroscopic, and polariscopic.

It was very generally noticed that the structure of the corona was radiated, and several rifts were seen therein. A comparison of photographs at different stations, indicates a fixity in these rifts which renders it certain that they existed at an immense distance from the observers; in other words, that they were neither terrestrial, nor lunar, but, therefore, were solar. Of the results up to date, no better general review has appeared than that contained in De La Rue's address, at the British Association meeting of 1872. He says:—"If the rays and rifts were really atmospheric, it would hardly be possible that they should present the same appearance at different stations along the line of totality; indeed they would probably change their appearance every moment, even at the same station. If they are cis-lunar, the same appearances could not be recorded at distant stations. It is universally admitted that proof of the invariability of these markings, and especially of their identity, as seen at widely-separated stations, would amount to a demonstration of their extra-terrestrial origin. Eye-sketches cannot be depended on: the drawings made by persons standing side by side differ often to an extent that is most perplexing. Now photographs have undoubtedly as yet failed to catch many of the faint markings and delicate details; but their testimony, as far as it goes, is unimpeachable. In 1870, Lord Lindsay at Santa Maria, Professor Winlock at Jerez, Mr. Brothers at Syracuse, obtained pictures, some of which, on account partly of the unsatisfactory state of the weather, could not compare with Mr. Brothers's picture, obtained with an instrument of special construction; but all show one deep rift especially, which seemed to cut down through both the outer and inner corona clear to the limb of the Moon. Even to the naked eye it was one of the most conspicuous features of the eclipse. Many other points of detail

also come out identical in the Spanish and Sicilian pictures, but whatever doubts may have still existed in regard to the inner corona, were finally dispelled by the pictures taken in India in 1871, by Colonel Tennant and Lord Lindsay's photographic assistant Mr. Davis. None of the photographs of 1871 shows so great an extension of the corona as is seen in Mr. Brothers's photograph taken at Syracuse in 1870; but, on the other hand, the coronal features are perfectly defined on the several pictures, and the number of the photographs renders the value of the series singularly great . . . We have in all the views the same extensive corona, with persistent rifts similarly situated. Moreover, there is additional evidence indicated by the motion of the Moon across the solar atmospheric appendages, proving, in a similar manner as in 1860 in reference to the protuberances, the solar origin of that part of the corona."

Mr. De La Rue's general summary of the whole matter as things stood in 1872, is conveyed in the following words:—"The great problem of the solar origin of that portion of the corona which extends more than a million of miles beyond the body of the Sun, has been, by the photographic observations of Colonel Tennant and Lord Lindsay in 1871, set finally at rest, after having been the subject of a great amount of discussion for some years[k]."

There is yet another recent total eclipse of the Sun, which requires to be referred to, namely that of April 16, 1874, visible only in South Africa. No very important preparations were made in anticipation of it, but it so happened that one highly competent observer was at hand to deal with it, and some observations recorded by him combined with others made under his directions, resulted in the elucidation of certain matters connected with the corona which deserve attention. It is to Mr. E. J. Stone, Director of the Cape Observatory, that allusion is here made[l]. He stationed himself at a place called Klipfontein in Namaqualand, Lat. 29° 14′ S.; Long. $1^h\ 10^m\ 40^s$ E. Parties of amateurs instructed by him made observations at the same place, at Maseru in British Basutoland, and at Radloff in West Griqualand, Lat. 28° 41′ 40″ S., Long. $1^h\ 38^m\ 42^s$ E. The distance between the two extremities of this chain of stations was more than 500 miles. A comparison

[k] *British Association Report*, 1872, Transactions of the Sections, pp. 6, 7.
[l] *Mem.* R.A.S., vol. xlii. p. 35. 1875.

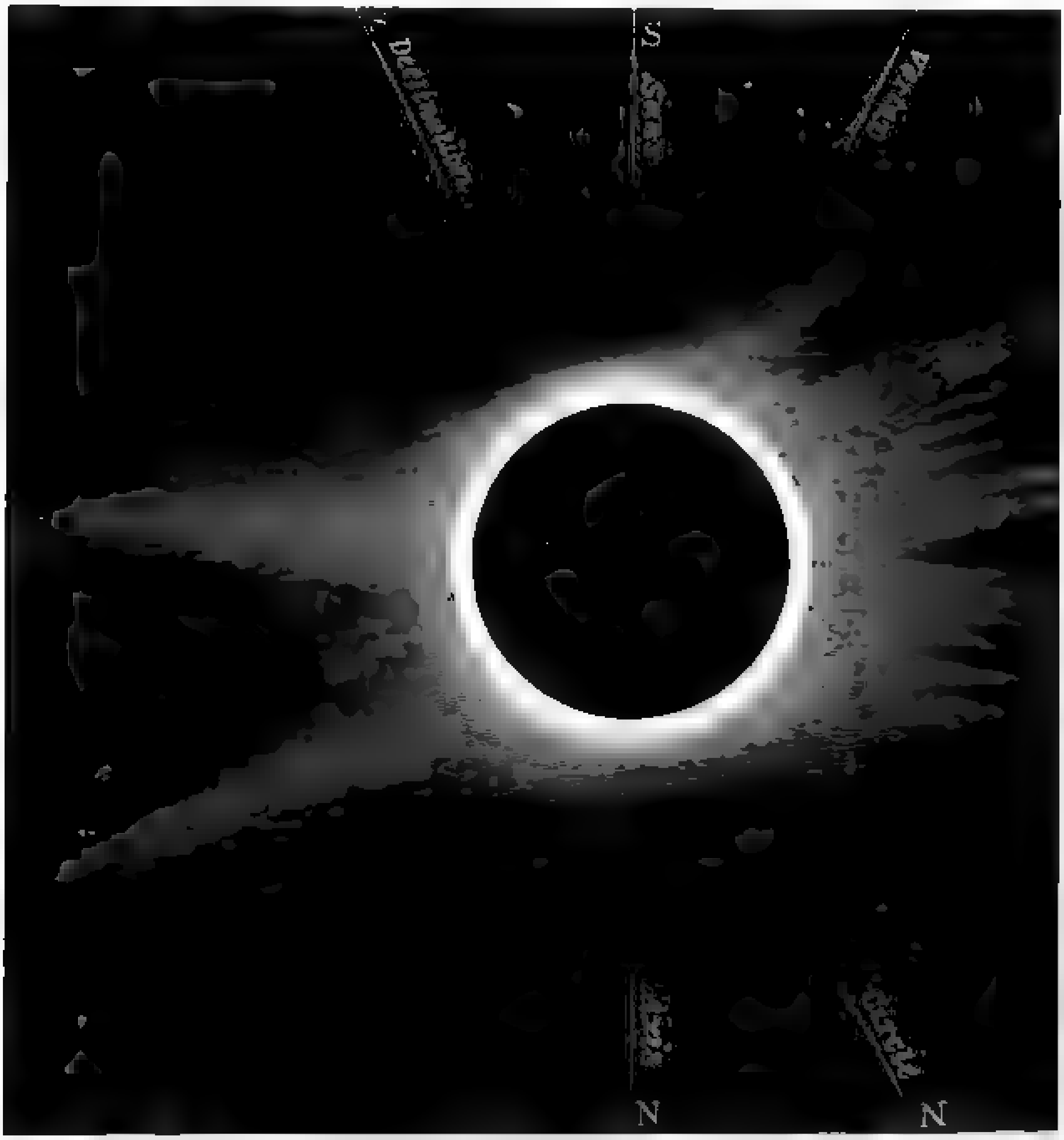
of drawings made at places thus remote from each other, and at intervals of absolute time extending to 10 minutes, exhibits such an identity in the general shape of the corona as, in Mr. Stone's opinion, to prove "the solar origin and cosmical character of the outer corona. The want of coincidence in the positions of the general extensions of the inner corona, with the main branches of the outer corona, is an additional argument against the atmospheric origin of the outer corona."

The 1874 observations reveal important information respecting the contour of both the inner and the outer coronas, and seem likely to lead ere long to much more accurate conceptions respecting the dynamical circumstances of the corona as a whole. A drawing by Mr. H. Hall, C. E., represents the inner corona as a rectangle with the corners rounded off, and placed with the shorter sides of the rectangle nearly parallel to the axis of the Sun. Similarly although the outline of the outer corona was very irregular, it is not difficult to detect signs that its general dimensions measured in one direction were sensibly greater than in another direction at right angles to the first, the shorter diameter being exactly coincident with the Sun's axis and therefore nearly coincident with the shorter diameter of the inner corona. It may be difficult to say exactly what this implies, but assuredly we have here some indications of the corona being an appendage of the Sun in a much more definite sense than has hitherto been supposed, and of an axial rotation thereof resulting, as is usual in such cases, in a polar compression and an equatorial bulging out.

The South African observations to which attention is now being called furnish a caution which in some measure applies to other astronomical observations besides those of eclipses. With the annexed drawing exhibiting the outer corona [fig. 87], and executed at Maseru, Basutoland, agrees very well Miss Alice Hall's drawing executed at Klipfontein. But Mr. H. Hall's drawing is radically different from his sister's, though they were sitting side by side. The irregular extensions of the outer corona in several directions noticed by Mr. Bright and Miss Hall are wholly wanting in Mr. Hall's sketch, which, as mentioned above, gives the corona the shape of an almost perfect rectangle with the corners rounded off and a slight curved indentation in each of the sides. On these discrepancies Mr. Stone writes as follows:—

"I was astonished to find when, after the termination of the totality, I looked at the drawings, that there was not a trace of any similarity between them. Mr. Hall's outline did not extend to quite 11′ from the moon's limb. Miss Hall's extended to 1° 40′ from the Moon's limb in one direction, and to very large angular distances in other directions. I had myself examined with the spectroscope the corona to a

Fig. 87.



THE TOTAL ECLIPSE OF THE SUN OF APRIL 16, 1874: Naked-eye view of the outer Corona. (*H. E. R. Bright.*)

distance from the Moon's limb more than 5 times as great as the corona represented in Mr. Hall's drawing. I was able to speak of the general accuracy of Miss Hall's drawing of the branches . . . and my wife, who had seen the eclipse well through the finder, expressed her agreement also with the general accuracy of Miss Hall's drawing. But Mr. Hall's skill and practice as a mechanical draughtsman entitled his drawing

to be received with every confidence, and he was perfectly satisfied with the drawing made. If the apparent discrepancy between these drawings could be explained, the explanation would probably throw much light upon the apparent discrepancies between drawings made at previous eclipses which had been taken to indicate such changes in the outer corona that, if their reality could be accepted, the optical character of this part of the corona would be established. The short eye-view which I took of the eclipse affords, I believe, a key to the true explanation. The inner corona (which at the time of the eclipse I was prepared to call the chromosphere) was so much brighter than the outer corona (or, as I at the time considered it, the corona) that it required some effort to transfer the attention from the inner to the outer corona. The outer corona was however bright enough to be well seen when once it had attracted the observer's attention [m]."

It may be mentioned as an incidental result of Mr. Stone's observations that having examined the Sun's spectrum near the Moon's limb during the partial phase, he could not detect the presence of any additional absorption lines "nor any sensible change in the appearance of any of the Fraunhofer lines in the spectrum near the Moon's limb, from that presented at considerable distances from it. I consider that these observations afford another proof that there does not exist any sensible atmosphere around the Moon, and that we are warranted in assuming that no sensible refraction of the rays of light from the Sun or corona can take place at the Moon, and that no modification of the visible corona can be attributed to any such cause."

As regards the circumstances of the corona considered with reference to the axis of Sun, Mr. Ranyard informs me that an exhaustive review of the observations of recent Eclipses leads him to the conclusion that whereas in 1851, 1860, 1868, 1869, 1871, and 1874 the coronas seen may be described as "symmetrical," the corona seen in 1870 must be termed a "non-symmetrical" corona. Why this diversity it is not easy to say.

[m] *Mem.* R.A.S., vol. xlii. p. 46. 1875.

CHAPTER VII.

HISTORICAL NOTICES[a].

Eclipses recorded in Ancient History.—Eclipse of 584 B.C.—*Eclipse of* 556 B.C.—*Eclipse of* 479 B.C.—*Eclipse of* 430 B.C.—*Eclipse of* 309 B.C.—*Allusions in old English Chronicles to Eclipses of the Sun.*

THE earliest eclipse on record is one given in the Chinese history named the *Chou-king;* it is supposed that it is the solar eclipse of Oct. 13, 2128 B.C.[b] which is there alluded to.

One of the most celebrated eclipses of the Sun recorded in history is that which occurred in the year 585 B.C. It is notable, not only on account of its having been predicted by Thales, who was the first ancient astronomer who gave the true explanation of the phenomena of eclipses, but because it seems to fix the precise date of an important event in ancient history. Herodotus describes a war that had been carried on for some years between the Lydians and the Medes; and gives an account of the following circumstances which led to its premature termination:—

"As the balance had not inclined in favour of either nation, another engagement took place in the 6th year of the war, in the course of which, just as the battle was growing warm, day was suddenly turned into night (*συνήνεικε ὥστε τῆς μάχης συνεστεώσης τὴν ἡμέρην ἐξαπίνης νύκτα γενέσθαι*). This event had been foretold to the Ionians by Thales of Miletus, who predicted for it the very year in which it actually took place. When the Lydians and Medes observed the change they ceased fighting, and were alike anxious to conclude peace." Peace was accordingly agreed upon and cemented by a twofold marriage. "For without some strong bond, there is little security to be found in men's covenants."

So adds the historian[c]. The exact date of this interesting

[a] See the Rev. S. J. Johnson's *Eclipses past and future.*

[b] *Mem.* R.A.S., vol. xi. p. 47. 1840.

[c] Herod., lib. i. cap. 74.

event was long disputed, and the solar eclipses of 610, 593, and particularly 585 B.C., were each fixed upon as the one mentioned by Herodotus; and it is only within the last few years that the point has been finally settled in favour of the last-mentioned eclipse, and that chiefly through the researches of Sir G. B. Airy, who gives, as the date of the eclipse in question, May 28, 585 B.C.[d] This is reconcileable with the statements of Cicero and Pliny.

Another important ancient eclipse is that mentioned by Xenophon, in the *Anabasis*, as having led to the capture by the Persians of the Median city Larissa. In the retreat of the Greeks on the eastern side of the Tigris, not long after the seizure of their commanders, they crossed the river Zapetes, and also a ravine, and then came to the Tigris. At this place, according to Xenophon, there stood—

"A large deserted city called Larissa, formerly inhabited by the Medes; its wall was 25 feet thick, and 100 feet high; its circumference 2 parasangs; it was built of burnt brick on an understructure of stone 20 feet in height. When the Persians obtained the empire from the Medes, the king of the Persians besieged the city, but was unable by any means to take it till a cloud having covered the Sun and caused it to disappear completely, the inhabitants withdrew in alarm, and thus the city was captured[e]."

The historian then goes on to say that the Greeks in continuing their march, passed by another ruined city named Mespila. The minute description given by Xenophon enabled Layard, Felix Jones, and others, to identify Larissa with the modern Nimrùd, and Mespila with Mosul. It is plain that the phenomenon to which the Greek author refers as having led to the capture of the above-mentioned city, was no other than a total eclipse of the Sun. Airy arrived at the conclusion that this eclipse occurred on May 19, 557 B.C.[f]

In the same year as that in which, according to the common account, the battle of Salamis was fought (480 B.C.), there occurred a phenomenon which is thus adverted to:—

"At the first approach of spring the army quitted Sardis, and marched towards Abydos; at the moment of its departure the Sun suddenly quitted its place in the heavens and disappeared (ὁ ἥλιος ἐκλιπὼν τὴν ἐκ τοῦ οὐρανοῦ ἕδρην ἀφανὴς ἦν), though

[d] *Phil. Trans.*, vol. cxliii. pp. 191–197. 1853. *Month. Not.*, vol. xviii. p. 143. March 1858.

[e] *Anab.*, lib. iii. cap. 4. § 7.

[f] *Month. Not.*, vol. xvii. p. 234. June 1857.

there were no clouds in sight, and the sky was quite clear; day was thus turned into night (ἀντὶ ἡμέρης τε νὺξ ἐγένετο)[g]."

This account, interpreted as a record of a total solar eclipse, has given great trouble to chronologers, and it is still uncertain to what eclipse reference is made. If Hind's theory that the eclipse of Feb. 17, 478 B.C. is the one referred to, is sound, we must consider that the battle of Salamis is an event less remote by 2 years than has usually been supposed. Airy "thinks it extremely probable" that the narrative relates to the total eclipse of the *Moon*, which happened 478 B.C., March 13^d 15^h G.M.T.[h]

A total eclipse of the Sun, supposed to have been that of August 3, 431 B.C., nearly prevented the Athenian expedition against the Lacedæmonians, but a happy thought occurring to Pericles, commander of the forces belonging to the former nation, the difficulty was got over.

"The whole fleet was in readiness, and Pericles on board his own galley, when there happened an eclipse of the Sun. The sudden darkness was looked upon as an unfavourable omen, and threw the sailors into the greatest consternation. Pericles observing that the pilot was much astonished and perplexed, took his cloak, and having covered his eyes with it, asked him if he found anything terrible in that, or considered it as a bad presage? Upon his answering in the negative, he said, 'Where is the difference, then, between this and the other, except that something bigger than my cloak causes the eclipse[i]?'"

Thucydides says:—

"In the same summer, at the beginning of a new lunar month (at which time alone the phenomenon seems possible), soon after noon the Sun suffered an eclipse; it assumed a crescent form, and certain of the stars appeared: after a while the Sun resumed its ordinary aspect[k]."

An ancient eclipse, known as that of Agathocles, has also been investigated by Sir G. B. Airy, and previously by Baily. It took place on August 14, 310 B.C. This eclipse is, according to ancient writers, associated with an interesting historical event. Agathocles, having been closely blockaded in the harbour of Syracuse by a Carthaginian fleet, took advantage of a temporary relaxation in the blockade, occasioned by the absence of the enemy in quest of a relieving fleet, and quitting the harbour of Syracuse, he landed

g Herod., lib. vii. cap. 37. Plutarch, *Pelopidas*, 31. Diod. Sic., lib. xv. cap. 80. Grote, *Hist. of Greece*, vol. x. p. 424.

h *Phil. Trans.*, vol. cxliii. p. 197. 1853. See also Blakesley's *Herod.*, *in loco.*

i Plutarch, *Vita Periclis.*

k Thucyd., lib. ii. cap. 28.

on the neighbouring coast of Africa, at a point near the modern Cape Bon, and devastated the Carthaginian territories. It is stated that the voyage to the African coast occupied 6 days, and that an eclipse (which from the description was manifestly total) occurred on the 2nd day. Diodorus Siculus says that the stars were seen [l], so that no doubt can exist as to the totality of the eclipse. Baily, however, found that there existed an irreconcileable difference between the calculated path of the shadow and the historical statement, a space of about 180 geographical miles appearing between the most Southerly position that can be assigned to the fleet of Agathocles and the Northerly limit of the phase. "To obviate this discordance, it is only necessary to suppose an error of about 3′ in the computed distances of the Sun and Moon at conjunction, a very inconsiderable correction for a date anterior to the epoch of the Tables by more than 21 centuries [m]."

In the writings of the early English chroniclers are to be found numerous passages relating to total eclipses of the Sun. The eclipse of August 2, 1133, was considered a presage of misfortune to Henry I: it is thus referred to by William of Malmesbury:—

"The elements manifested their sorrow at this great man's last departure. For the Sun on that day at the 6th hour shrouded his glorious face, as the poets say, in hideous darkness, agitating the hearts of men by an eclipse; and on the 6th day of the week, early in the morning, there was so great an earthquake that the ground appeared absolutely to sink down; an horrid noise being first heard beneath the surface [n]."

The same writer, speaking of the total eclipse of March 20, 1140, says:—

"During this year, in Lent, on the 13th of the calends of April, at the 9th hour of the 4th day of the week, there was an eclipse, throughout England, as I have heard. With us, indeed, and with all our neighbours, the obscuration of the Sun also was so remarkable, that persons sitting at table, as it then happened almost everywhere, for it was Lent, at first feared that Chaos was come again: afterwards learning the cause, they went out and beheld the stars around the Sun. It was thought and said by many, not untruly, that the king [Stephen] would not continue a year in the government [o]."

[l] Diodor. Sic., lib. xx. cap. 1. Justin., lib. xxii. cap. 6.

[m] *Phil. Trans.*, vol. cxliii. pp. 187-191. 1853.

[n] *Hist. Nov.*, lib. i.

[o] *Hist. Nov.*, lib. ii. See also *Sax. Chron.*, Thorpe's Trans., p. 233. 8vo. London, 1861.

CHAPTER VIII.

ECLIPSES OF THE MOON.

Lunar Eclipses of less interest than Solar ones.—Summary of facts connected with them.—Peculiar circumstances noticed during the Eclipse of March 19, 1848.—Observations of Forster.—Wargentin's remarks on the Eclipse of May 18, 1761.—Kepler's explanation of these peculiarities being due to Meteorological causes.—Chaldæan observations of Eclipses.—Other ancient Eclipses.—Anecdote of Columbus.

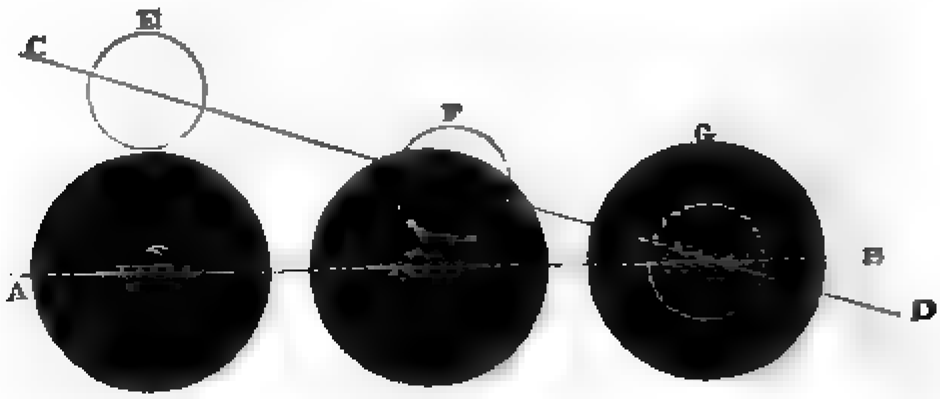
AN eclipse of the Moon, though inferior in importance to one of the Sun, is nevertheless by no means devoid of interest; it is either partial or total[a], according to the extent to which our satellite is immersed in the Earth's shadow. In a total eclipse the Moon may be deprived of the Sun's light for $1^h\ 50^m$, and reckoning from the first to the last contact of the penumbra, the phenomenon may last $5^h\ 30^m$, but this is the outside limit. The obscuration is found to last longer than calculation fixes it. This is due to the fact that no account is taken in the calculations of the denser strata of the atmosphere through which the rays have to pass, which cause an obstructive effect analogous to that of the solid matter of the Earth. From numerous observations made during the eclipse of Dec. 26, 1833, Beer and Mädler found that the apparent breadth of the shadow was increased by $\frac{1}{50}$ on account of the terrestrial atmosphere. "Owing to the ecliptic limits of the Sun exceeding those of the Moon, there are more eclipses of the former luminary than of the latter; but on account of the comparatively small extent of the Earth's surface to which

[a] But never annular, because the diameter of the Earth's shadow, at the greatest possible distance of the Moon from the Earth, is always in excess of the diameter of the lunar disc.

a solar eclipse is visible, the eclipses of the Moon are more frequently seen at any particular place than those of the Sun."

Fig. 88 is designed to illustrate the different conditions of eclipses of the Moon. A B is the ecliptic, C D the Moon's path. The 3 black circles are imaginary sections of the Earth's shadow, when in 3 successive positions in the ecliptic. If the conjunction

Fig. 88.



Conditions of Eclipses of the Moon.

in longitude of the Earth and Moon occurs when the Moon is at E, it escapes eclipse; if the Moon is at F, it suffers a *partial* obscuration, but if the Moon is at or very near its node, indicated by G, it will be wholly involved in the Earth's shadow, and a *total* eclipse will be the result.

Whereas solar eclipses always begin on the Western side and go off on the Eastern, lunar eclipses on the contrary commence on the Eastern side and go off on the Western.

Fig 89.

The Moon Partially Eclipsed, Feb. 6, 1860.

Even when most deeply immersed in the Earth's shadow, our satellite does not, except on rare occasions, wholly disappear, but may be generally detected with a telescope (and frequently with the naked eye), having a dull red or coppery colour. This was exemplified in a very remarkable manner in the case of the eclipse of March 19, 1848, on which occasion the Moon was seen so clearly that many persons doubted the reality of the eclipse.

Mr. Forster, who observed the eclipse at Bruges, writes as follows:—

"I wish to call your attention to the fact which I have clearly ascertained, that during the whole of the late eclipse of March 19, the shaded surface presented a luminosity quite unusual, probably about three times the intensity of the mean illumination of the eclipsed lunar disc. The light was of a deep red colour. During the totality of the eclipse, the light and dark places on the face of the Moon could be almost as well made out as on an ordinary dull moonlight night, and the deep red colour where the sky was clearer was very remarkable from the contrasted whiteness of the stars. My observations were made with different telescopes; but all presented the same appearance, and the remarkable luminosity struck every one. The British Consul at Ghent, *who did not know there was an eclipse*, wrote to me for an explanation of the blood-red colour of the Moon at 9 o'clock [b]."

As a complement to this observation, I may quote one by Wargentin of the total eclipse of May 18, 1761. He says that 11^m after the commencement of the phase—

"The Moon's body had *disappeared so completely, that not the slightest trace of any portion of the lunar disc could be discerned either with the naked eye or with the telescope*, although the sky was clear, and the stars in the vicinity of the Moon were distinctly visible in the telescope [c]."

The red hue was long a phenomenon for which no explanation could be found; by some it was considered to be due to a light naturally inherent to the Moon's surface, but Kepler was the first to offer a more scientific explanation. He shewed that the phenomenon was a direct result of the refraction of the Earth's atmosphere, which had the effect of turning the course of the solar rays passing through it, causing them to fall upon the Moon even when the Earth was actually interposed between them and the Sun. The deep red colour of the Moon's surface arises from the absorption of the blue rays of light in passing through the terrestrial atmosphere, in the same manner as the Western sky is frequently seen to assume a ruddy hue when illuminated in the evening by the solar rays. On account of the variable meteorological condition of our atmosphere the quantity of light actually

[b] *Month. Not.*, vol. viii. p. 132. March 1848.

[c] *Phil. Trans.*, vol. li. p. 210. 1761. The original runs thus: "Tota luna, ita prorsus disparuerat, ut nullum ejus vestigium, vel nudis, vel armatis oculis, sensibile restaret, cœlo licet sereno, et stellis vicinis in tubo conspicuis." Other eclipses, where the same thing occurred, took place on June 15, 1620 (Kepler, *Epist. Ast.*, p. 825); April 25, 1642 (Hevelius, *Selenog.*, p. 117); and June 10, 1816 (Beer and Mädler).

transmitted is liable to considerable fluctuations, and hence arises a corresponding variation in the appearances presented by the Moon's surface during her immersion in the Earth's shadow. If the portion of the atmosphere through which the solar rays have to pass is everywhere tolerably free from vapour, the red rays will be almost wholly absorbed, but not so the blue, and the illumination will be too feeble to render the Moon's surface visible: as in the instances cited in note [c], p. 225. If, on the other hand, the region of the atmosphere through which the solar rays pass be everywhere highly saturated, the red rays will be transmitted to the Moon in great abundance, and its surface will consequently be highly illuminated. Such was the case in the eclipse of March 1848 already referred to. If, moreover, the region of the atmosphere through which the rays pass be saturated only in some parts and not in others, it follows that some portions of the Moon's disc will be invisible whilst others will be more or less illuminated. Such an occurrence was seen by Kepler [d] on Aug. 16, 1598, and by Sir J. Herschel on Oct. 13, 1837.

The celebrated African explorers, the Landers, graphically describe what took place on the occasion of the eclipse of the Moon of Sept. 2, 1830. They say:—

"The earlier part of the evening had been mild, serene, and remarkably pleasant. The Moon had arisen with uncommon lustre, and being at the full, her appearance was extremely delightful. It was the conclusion of the holidays, and many of the people were enjoying the delicious coolness of a serene night, and resting from the laborious exertions of the day; but when the Moon became gradually obscured, fear overcame every one. As the eclipse increased they became more terrified. All ran in great distress to inform their sovereign of the circumstance, for there was not a single cloud to cause so deep a shadow, and they could not comprehend the nature or meaning of an eclipse. Groups of men were blowing on trumpets, which produced a harsh and discordant sound; some were employed in beating old drums; others again were blowing on bullocks' horns. The diminished light, when the eclipse was complete, was just sufficient for us to distinguish the various groups of people, and contributed in no small degree to render the scene more imposing. If a European, a stranger to Africa, had been placed on a sudden in the midst of the terror-struck people, he would have imagined himself among a legion of demons, holding a revel over a fallen spirit."

It is to the Chaldæans that we owe the earliest recorded observations of lunar eclipses, as mentioned by Ptolemy. The first of

[d] *Ad Vitell. Paralipom.*

has been regarded by some as indicative of Volcanic action, but this seems mere fancy. Prof. Powell, with more show of reason, suggested that diffraction of light had something to do with the matter, but it is an objection to this theory that it presupposes the invariable centrality of the white spot; now the white spot, though often, is not always coincident in position with the centre of the planet's disc, and therefore Huggins rejects the hypothesis. It might conceivably have its origin in the internal reflection of light in a Huyghenian Eye-piece.

We now come to the transits of Venus, which are more important and more rare. In the year 1627 Kepler completed the *Rudolphine Tables*, and being thus in a position to calculate the motions of the planets with far more certainty than had ever been attained before, he betook himself diligently to the work. The first result was, that he ascertained that during 1631 both Mercury and Venus would traverse the Sun's disc, the former on Nov. 7 and the latter on Dec. 6; which information he published in a little tract in 1629[k]. Of the transit of Mercury I have already spoken. With reference to that of Venus, Gassendi made preparations for observing it; and though Kepler's calculations were to the effect that the ingress would not take place till near sunset, the French astronomer, anticipating the possibility of the calculated times being too late, (as had been the case with Mercury a few weeks previously,) prepared to commence his watch on Dec. 4, though bad weather prevented him seeing the Sun till the 6th. He sought unsuccessfully for the planet both on that and on the following day, and it is now well known that the transit took place on the night of the 6–7th.

The next transit of Venus (the first actually observed) took place on Nov. 24, 1639 (O. S.) Kepler did not anticipate it, for he said that none would take place between 1631 and 1761, and so the honour both of predicting and of observing it rests with a young English amateur, the Rev. Jeremiah Horrox, curate of Hoole, a village in Lancashire, 15 miles N. of Liverpool. Horrox had been engaged in computing the places of the planets by the aid of Lansberg's Tables. Finding that these gave very erroneous results

[k] *Admonitio ad Astronomos rerumque celestium studiosos, de miris rarisque anni* 1631 *phænomenis, Veneris puta et Mercurii in solem incursu.* Lipsiæ, 1629.

he discarded them for Kepler's, from which he found that on the above Nov. 24, Venus, in passing its inferior conjunction, would cross the heavens a little *below* the Sun. As Lansberg's Tables indicated that the planet would cross the upper part of the solar disc, he hoped that a mean of the two results, so to speak, might be looked for, and that he should see the planet actually *on* the Sun, towards the lower extremity of its disc: further calculation assured him that his anticipation would turn out to be correct. Owing to the shortness of the interval that would elapse previous to the actual occurrence of the transit he was unable to give much publicity to the result at which he had arrived; indeed all that he seems to have done was to inform his friend William Crabtree, an enthusiastic amateur like himself, who resided at Broughton, near Manchester, not many miles distant from Hoole.

Horrox prepared to watch for the planet by transmitting the image of the Sun through a telescope on to a screen in a darkened room. His final calculations gave 3^h P.M. on Nov. 24 as the time of conjunction of the centres of the Sun and planet; but fearing to be too late, he commenced his scrutiny of the Sun on Nov. 23. On the following day he began his observations at Sunrise, and continued them till the hour of Church service. (It was Sunday.) As soon as he was again at leisure—that is to say at 3^h 15^m P.M.—he resumed his labours, and, to quote his own words, "At this time an opening in the clouds, which rendered the Sun distinctly visible, seemed as if Divine Providence encouraged my aspirations; when, O most gratifying spectacle! the object of so many earnest wishes, I perceived a new spot of unusual magnitude, and of a perfectly round form, that had just wholly entered upon the left limb of the Sun, so that the margin of the Sun and spot coincided with each other, forming the angle of contact." Owing to the near approach of Sunset, Horrox was unable to observe the planet longer than half an hour; but at any rate he had seen it, and had been able to take some measurements[1].

Crabtree had also made arrangements for observing the phenomenon. The Sun was, however, obscured during the whole of the day, and he had given up in despair all hope of seeing the

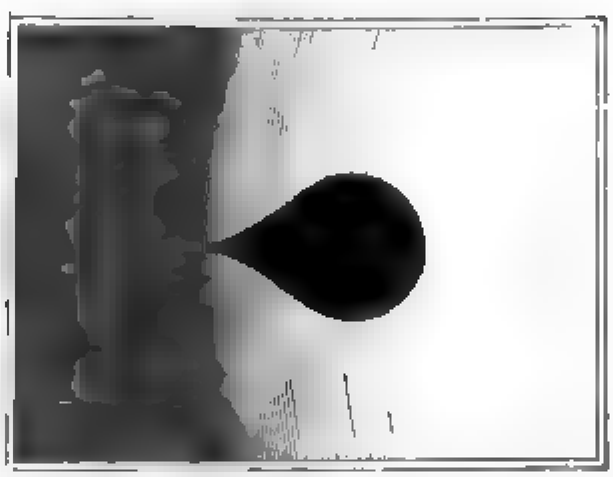
[1] Whatton, *Memoir of Horrox*, pp. 109-135.

transit, when, just before Sunset, the clouds broke up, and, hastening to his observing chamber, he saw, to his infinite delight, Venus depicted on the Sun's disc transmitted on to a screen. He was, according to his own account, so entranced by the spectacle that ere he recovered his self-possession the clouds had again enshrouded the Sun, and he saw the planet no more. He subsequently found that a rough diagram, which he drew from memory, agreed well with one drawn by Horrox.

No other transit occurred till June 5, 1761 : this was observed in many parts of the world for the purpose of ascertaining, in accordance with the special suggestion of Halley, the solar parallax. But the results of the different observations were not satisfactory.

Extensive preparations were made for observing the transit of June 3, 1769, and King George III despatched, at his own expense, a well-equipped expedition to Tahiti under the command of the celebrated navigator Captain Cook, R.N. Many of the Continental Powers followed the example of England, and astronomers were sent out to the most advantageous points for observation. The chief of these were St. Petersburg, Pekin, Orenburg, Iakutsk, Manilla, Batavia, for the egress; and Cape Wardhus, Kola and Kajeneburg in Lapland, Point Venus in Tahiti, and Fort Prince of Wales and St. Joseph in California, for the entire phenomenon. The observations were long looked upon as trustworthy, but astronomers eventually came to the conclusion that an important correction in the final result must be accepted [m]. Accordingly the transit of Dec. 9, 1874 was awaited with special eagerness.

Fig 91.



VENUS DURING ITS TRANSIT IN 1769.

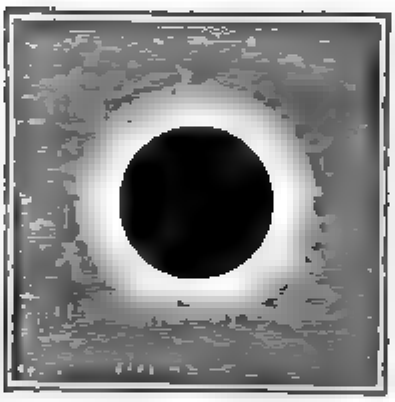
Some phenomena were seen in connexion with the transits of 1761 and 1769 which require a passing mention. It was noticed on both occasions, and by numerous observers, that the interior contact of the planet with the Sun did not take place regularly at the ingress,

[m] See p. 2 *ante*.

but that the planet appeared for a short time after it had entered upon the disc of the Sun to be attached to the Sun's limb by a dark ligament. A similar phenomenon was noticed at the egress. It was also found that even after the planet had got wholly clear of the Sun's limb it did not acquire circularity for several seconds[n]. Lalande suggested[o] that irradiation was the cause of these phenomena, and this is doubtless the true explanation.

It was remarked by several observers of the transits of 1761 and 1769, that, both at the ingress and egress, the portion of the limb of the planet which was not then projected on the Sun was rendered perceptible by reason of a faint ring of light which surrounded it. More than one observer noticed a ring round Venus when it was entirely *within* the disc of the Sun, similar, it would seem, to that which has been seen to surround Mercury when in the same situation. Dunn states that this annulus had a breadth of 5″ or 6″, that it was somewhat dusky towards the limb of the planet, and that its outer margin was slightly tinged with blue. Hitchins describes it as excessively white and faint, and brightest towards the body of the planet. Nairne speaks of it as brighter and whiter than the body of the Sun. A comparison of the different accounts seems to shew that the above-described rings are *not* identical, but no sufficient explanation has been offered to account for either, though the latter has been supposed to indicate the existence of an atmosphere around the planet[p].

Fig. 92.



Venus during its Transit in 1769.

One observer of the transit of 1769 is stated to have seen a light on the disc possibly similar to that occasionally noticed on Mercury during its transits[q].

A ring of light was seen by many observers round Venus during the transit of Dec. 8, 1874, which the engraving above seemingly would represent equally well[r].

[n] See *Phil. Trans.*, 1761, 1768, 1769, 1770, also *Mém. Acad. des Sciences* for the same years.

[o] *Mém. Acad. des Sciences*, 1770, p. 409.

[p] For references for all these statements, see Grant's *Hist. of Phys. Ast.*, p. 431.

[q] *Append. Ad. Ephem. Astron.*, 1766, p. 62.

[r] *Month. Not.*, vol. xxxv. p. 133 (Jan. 1875); p. 310 (March 1875).

CHAPTER XI.

OCCULTATIONS.

How caused.—Table annually given in the "Nautical Almanac."—Occultation by a young Moon.—Effect of the Horizontal Parallax.—Projection of Stars on the Moon's disc.—Occultation of Saturn, May 8, 1859.—Occultation of Jupiter, January 2, 1857.—Historical notices.

WHEN any celestial object is concealed by the interposition of another, it is said to be *occulted*, and the phenomenon is called an *occultation*. Strictly speaking, an eclipse of the Sun is an occultation of that luminary by the Moon, but usage has given to it the exceptional name of "eclipse." The most important phenomena of this kind are the occultations of the planets and larger stars by the Moon, but the occultation of one planet by another, on account of the rarity of such an occurrence, is exceedingly interesting. Inasmuch as the Moon's apparent diameter is about ½°, it follows that all stars and planets situated in a zone extending ¼° on each side of her path will necessarily be occulted during her monthly course through the ecliptic, and parallax will have the effect of further increasing considerably the breadth of the zone of stars subject to occultation. The great brilliancy of the Moon entirely overpowers the smaller stars, but the disappearances of the more conspicuous ones can be observed with a telescope, and a table of them is inserted every year in the *Nautical Almanac*.

It must be remembered that the disappearance always takes place at the limb of the Moon which is presented in the direction of its motion. From the epoch of its New to that of its Full phase the Moon moves with the dark edge foremost, and from the epoch of its Full to that of its New phase with the illuminated edge foremost: during the former interval, therefore, the objects occulted disappear at the dark edge, and reappear at the illuminated edge;

and during the latter period they disappear at the illuminated, and reappear at the dark edge. If the occultation be watched when the star disappears on the dark side of the Moon, that is to say during the first half of a lunation, and preferably when the Moon is not more than 2 or 3 days old, the disappearance is extremely striking, inasmuch as the object occulted seems to be suddenly extinguished at a point of the sky where there is apparently nothing to interfere with it. Wargentin relates that on May 18, 1761, he saw an occultation of a star by the Moon during a total eclipse of the latter. He says that the star disappeared "more quickly than the twinkling of an eye[a]." In consequence of the effect of parallax, the Moon, as seen in the northern hemisphere, follows a path different from that which it appears to take as seen in the southern hemisphere; it happens, therefore, that stars which are occulted in certain latitudes are not occulted at all in others, and of those which are occulted the duration of invisibility, and the moment and place of disappearance and reappearance, are different.

I must not omit a passing allusion to a circumstance occasionally noticed by the observers of occultations; namely, the apparent projection of the star *within* the margin of the Moon's disc.

Admiral Smyth gives an instance, under the date of October 15, 1829. He says:—

"I saw Aldebaran approach the bright limb of the Moon very steadily; but, from the haze, no alteration in the redness of its colour was perceptible. It kept the same steady line *to about* $\frac{3}{4}$ *of a minute inside the lunar disc,* where it remained, as precisely as I could estimate, $2\frac{1}{2}$ seconds, when it suddenly vanished. In this there could be no mistake, because I clearly saw the bright line of the Moon *outside* the star, as did also Dr. Lee, who was with me[b]."

Sir T. Maclear saw the same thing happen to the same star on October 23, 1831:—

"Previous to the contact of the Moon and star nothing particular occurred; but at that moment, and when I might expect the star to immerge, it advanced upon the Moon's limb for about 3 seconds, and to rather more than the star's apparent diameter, and then instantly disappeared[c]."

"This phenomenon seems to be owing to the greater propor-

[a] *Phil. Trans.*, vol. li. p. 210. 1761.
[b] *Mem.* R.A.S., vol. iv. p. 642. 1831. Other observers, Maclear included, saw the projection, though F. Baily and others did *not* see it.
[c] *Mem.* R.A.S., vol. v. p. 373. 1833.

tionate refrangibility of the white lunar light, than that of the red light of the star, elevating her apparent disc at the time and point of contact[d]."

In 1699 La Hire endeavoured to explain the apparition of stars on the Moon's disc by supposing that the true disc is accompanied by a parasitic light, or, as it was formerly termed, a circle of dissipation, which enlarges the star's apparent diameter, and through which it shews itself before passing behind the opaque part of the lunar globe. Arago accepts this theory with the explanation that the observer's eye-piece must be in imperfect focus, and that so the false disc is caused. The fact that some have and some have not seen the phenomenon he considered confirmatory of this explanation[e].

The present state of the question is that we do not possess any authentic explanation of the phenomenon.

A remarkable occurrence was noticed by Mr. Ralph Copeland, on the occasion of the occultation of *κ Cancri* on April 26, 1863:—

"About three-fourths of the light disappeared in the usual instantaneous manner; and after an interval of (as near as I can judge) rather more than half a second, the remaining portion disappeared."

Dawes regarded this as a decisive indication that the star was double, though he failed in verifying this surmise[f]. On Oct. 30, 1863, I watched the emersion of ψ^1 *Orionis*, and it was unquestionably not instantaneous.

An occultation of the planet Jupiter took place on January 2, 1857. A dark shadowy streak which appeared projected on the planet, from the edge of the Moon, was seen by several observers.

Fig. 93.

OCCULTATION OF JUPITER BY THE MOON: January 2, 1857.

[d] Smyth.

[e] *Pop. Ast.*, vol. ii. p. 348, Eng. ed. For other remarks on this phenomenon, see papers by Airy in *Mem.* R.A.S., vol. xxviii. p. 173, 1860, and *Month. Not.*, vol. xix. p. 208 (April 1859), and one by Stevelly discussing the Diffraction hypothesis in *Brit. Assoc. Rep.* 1845: Transactions of the Sections, p. 5. Also one by Plummer in *Month. Not.*, vol. xxxiii. p. 345 (March 1873).

[f] *Month. Not.*, vol. xxiii. p. 221 (May 1863).

Mr. W. Simms, Sen. thus described it:—

"The only remarkable appearance noticed by me during the emersion was the very positive line by which the Moon's limb was marked upon the planet; dark as the mark of a black-lead pencil close to the limb, and gradually softened off as the distance increased [g]."

A representation of this appearance, from a drawing by Lassall, is annexed [Fig. 93].

An occultation of the planet Saturn by the Moon took place on May 8, 1859. Dawes thus described it:—

"At the disappearance, the dark edge of the Moon was sharply defined on the rings and ball of the planet, without the slightest distortion of their figure. There was no extension of light along the Moon's limb. Even the satellites disappeared without the slightest warning, and precisely at the edge which was faintly visible.

"At the reappearance I could not perceive any dark shading contiguous to the Moon's bright edge, such as was seen by myself and several other observers on Jupiter on January 2, 1858 [Qy. 1857]. The dark belt south of the planet's equator was clearly defined up to the very edge; and there was no distortion of any kind, either of the rings or ball.

"The very pale greenish hue of Saturn contrasted strikingly with the brilliant yellowish light of the Moon [h]."

Mr. W. Simms, Jun. *did* see a dark shading on the planet contiguous to the Moon's bright edge; but in 1857 he failed to notice it.

In an occultation of Saturn on Oct. 30, 1825, Messrs. R. Comfield and J. Wallis plainly saw both one ansa and the ball *flattened* [i].

The earliest record which we have of an occultation is that of an occultation of Mars by the Moon, mentioned by Aristotle [k]. Kepler found that it occurred on the night of April 4, 357 B.C. [l]

Instances are on record of one planet occulting another, but these are of very rare occurrence. Kepler states that he watched an occultation of Jupiter by Mars on January 9, 1591. He also mentions that Mœstlin witnessed an occultation of Mars by Venus on October 3, 1590. Mercury was occulted by Venus on May 17, 1737 [m]. As these observations, with the exception of the last, were made before the invention of the telescope, it is possible

[g] *Month. Not.*, vol. xvii. p. 81 (Jan. 1857).

[h] *Ibid.*, vol. xix. p. 241 (May 1859). Other observations will be found at p. 238 of the same volume.

[i] *Mem.* R.A.S., vol. ii. p. 457. 1826.

[k] *De Cœlo*, lib. ii. cap. 12.

[l] *Ad. Vitell. Paralipom.*, p. 307.

[m] *Phil. Trans.*, vol. xl. p. 394. 1738.

that the one planet was not actually in front of the other, but only that they were so close together as to have had the appearance of being one object: as was the case with Venus and Jupiter on July 21, 1859.

Sometimes stars are occulted by planets. J. D. Cassini mentions the occultation of a star in Aquarius by Mars on October 1, 1672[n].

[n] See a paper on Occultations by A. C. Twining in *Amer. Journ. of Science*, 2nd ser., vol. xxvi. p. 15. July, 1858.

BOOK III.

PHYSICAL AND MISCELLANEOUS ASTRONOMICAL PHENOMENA.

CHAPTER I.

THE TIDES.

"O ye seas and floods, bless ye the LORD: praise Him, and magnify Him for ever."—*Benedicite.*

Introduction.—Physical cause of the Tides.—Attractive force exercised by the Moon.—By the Sun.—Spring Tides.—Neap Tides.—Summary of the principal facts.—Priming and Lagging.

MANY inhabitants of a maritime country like Great Britain have some acquaintance with the phenomena now to come under consideration, but beyond possessing a vague notion that the Moon has something to do with the tides, very few people have an intelligent idea of the way in which the tides are produced[a].

These phenomena are very frequently attributed to the attraction of the Moon, whereby the waters of the ocean are drawn towards that side of the Earth on which our satellite happens to be situated; in fact, that it is high water when the Moon is on or near the meridian of the place of observation.

This, though to a great extent true, by no means adequately represents the facts of the case, for high water is not only produced on the side of the Earth immediately under the Moon, but also on the opposite side at the same time. The coincident tides are

[a] See a paper by the late Sir J. Lubbock, in the *Companion to the Almanac* for 1830.

therefore separated from each other by 180°, or by half the circumference of the globe. Since the diurnal rotation of the Earth causes every portion of its surface to pass successively under the tidal waves in about 24^h, it follows that there are everywhere 2 tides daily, with an interval of about 12^h between each; whereas, if the common supposition were correct, there would be only one.

Such being the observed facts, and it being admitted that the attraction of the Moon gives rise to the upper tide, some further explanation must be sought to account for the lower one. The solution is extremely simple as an elementary conception: it is only necessary to bear in mind that not only does the Moon attract the upper mass of water, but also the solid globe itself, which is consequently compelled to recede from the waters beneath, leaving them behind, and in a sense heaped together.

Besides the influence of the Moon in elevating the waters of the ocean, that of the Sun is to some extent concerned, but it is much more feeble than that of the former, on account of the much greater distance of the solar globe. The mean distance of the Sun from the Earth is 382·846 times that of the Moon; its attractive power is consequently $(382{\cdot}846)^2$, or 146,571 times less; but inasmuch as the mass of the Sun exceeds that of the Moon in the ratio of 25,885,220 to 1, which is much greater than 146,571 to 1, it will naturally be said that surely the attraction exercised by the Sun exceeds that of the Moon in the same proportion that 25,885,220 exceeds 146,571[b]. This, however, is not the case, for a reason which will now be stated. It must be borne in mind that the tides are due solely to the *inequality* of the attraction in operation on different sides of the Earth, and that the greater that inequality is the greater will be the resulting tide, and *vice versâ*. The mean distance of the Sun from the Earth is 11,536 diameters of the latter, and consequently the difference between its distance from the one side of the Earth and from the other will be only $\frac{1}{11536}$ of the whole distance, while in the case of the Moon, whose mean distance is only 30 terrestrial diameters, the difference between the distances from one side and from the other, reckoned from the Moon, will be $\frac{1}{30}$ of the whole distance. The inequality of

[b] To avoid complicating the obviously crude argument in the text I leave certain things out of consideration.

the attraction (upon which the height of the tidal wave depends) is therefore much greater in the case of the Moon than of the Sun; the ratio, according to Newton, being 58 : 23, or about $2\frac{1}{2}$: 1.

We thus see that there are 2 kinds of tides, lunar and solar. When therefore the Sun, Moon, and Earth are in the same straight line with each other, that is to say, when it is either *New* or *Full Moon*, the attractions of the two former bodies act in the same line, and we have the highest possible tidal elevations, and what are known as "*spring* tides;" but when the Moon is in quadrature, or 90° from the Sun, its attraction acts along a line which is perpendicular to that along which the attraction of the Sun acts, the two tidal elevations are 90° apart, and we have the tides which are called "*neap*."

It may be convenient to state here a few general facts relating to the tides:—

1. On the day of New Moon, the Sun and Moon cross the meridian at the same time, *i.e.* at noon, and at an interval after their passage (varying according to the place of observation, but fixed and definite for each place) high water occurs. The water, having reached its maximum height, begins to fall, and after a period of $6^h\ 12^m$ attains a maximum depression; it then rises for $6^h\ 12^m$, and reaches a second maximum; falls for another interval of $6^h\ 12^m$, and rises again during a 4th interval of $6^h\ 12^m$.[c] It has therefore 2 maxima and 2 minima in a period of $24^h\ 48^m$, which is called a *tidal day*.

2. On the day of Full Moon, the Moon crosses the meridian 12^h after the Sun, *i.e.* at midnight, and the tidal phenomena are the same as in (1).

3. As time is reckoned by the apparent motion of the Sun, the solar tide always happens at the same hour at the same place, but the lunar tide, which is the greater, and thereby gives a character to the whole, happens $48^m\ 44^s$ later every day; it therefore separates Eastwards from the solar tide, at that rate, and gradually becomes later and later, till at the periods of the 1st and 3rd quarters of the Moon it happens at the same time as the low water of the solar tide: then the elevation of the high, and the depression of

[c] Practically this is somewhat incorrectly expressed, for it is found that the intermediate low water does not take place at the mean moment between the two tides, the waters usually taking a shorter time to rise than they do to fall.

the low water, will be the difference of the solar and the lunar tides, and the tide will be neap.

4. The difference in height between the high and low water is called the *range of the tide.*

5. The spring tides are highest, especially those which happen 36^h after the New, or Full Moon.

6. The neap tides are the lowest, especially those which happen 36^h after the Moon is in quadrature.

7. The interval of time from Noon to the time of high water at any particular place is the same on the days both of New and Full Moon, and is termed the "*Establishment of the port.*"

The reason why an interval of time elapses between the Moon's meridian passage and the time of high water is, that the waters of the ocean have to overcome a certain peculiar effect of friction, which cannot immediately be accomplished; it thus happens that the lunar tidal wave is not found immediately under the Moon, but follows it at some distance. Similar results ensue in the case of the solar wave. The tidal wave is also affected in another way, by the continued action of both these luminaries, and at certain periods of the lunar month is either accelerated or retarded in a way which will now be described: "In the 1st and 3rd quarters of the Moon, the solar tide is Westward of the lunar one; and consequently the actual high water (which is the result of the combination of the 2 waves) will be to the Westward of the place it would have been at if the Moon had acted alone, and the time of high water will therefore be accelerated. In the 2nd and 4th quarters, the general effect of the Sun is, for a similar reason, to produce a retardation in the time of high water. This effect, produced by the Sun and Moon combined, is called the *priming* and *lagging* of the tides. The highest spring tides occur when the Moon passes the meridian about $1\frac{1}{2}^h$ after the Sun; for then the maximum effect of the 2 bodies coincides." The "priming" and "lagging" effect deranges the average retardation, which from a mean value of 48^m may be augmented to 60^m or be reduced to 36^m.

The 2 tides following one another are also subject to a variation, called the *diurnal inequality*, depending on the daily change in declination of the Sun and Moon; the laws which govern it are, however, very imperfectly known.

Guillemin writes:—"The height of the tides again varies with

the declinations of the Moon and Sun; it is by so much greater as the two bodies are nearer the equator. Twice a year, towards March 21 and Sept. 22, the Sun is actually in the equator. If, at the same time, the Moon is near the same plane the tides which occur then are the highest of all. These are the *Equinoctial Spring Tides*, because the Earth is then at the vernal or autumnal equinox. On the other hand, the smallest tides take place towards the solstices, if the Moon attains its smallest or its greatest meridional height at the same time as the Sun. Lastly, the distances of the Moon and Sun from the Earth have also their influence on the height of the tides. Other things being equal, the height of a tide is greater or less, according as the attracting bodies are nearer to or farther from the Earth. Thus the tides of the winter solstice are higher than those of the summer one[d]."

[d] *The Heavens.* Eng. ed., p. 461.

CHAPTER II.

Local disturbing influences.—Table of Tidal ranges.—Influence of the Wind.—Experiment of Smeaton.—Tidal phenomena in the Pacific Ocean.—Remarks by Beechey.—Velocity of the great Terrestrial Tidal wave.—Its course round the Earth, sketched by Johnston.—Effects of Tides at Bristol.—Instinct of animals.—Tides extinguished in rivers.—Historical notices.

WE have hitherto been considering the tidal wave, on the supposition of the Earth being a perfect sphere covered with water to a uniform depth; but inasmuch as this is not the case, it follows that the actual phenomena of the tides are widely different and of a much more complicated character, owing to the irregular outline of the land, the uneven surface of the ocean bed, the action of winds, currents, friction, &c. The effects of these disturbing influences are rendered especially manifest in the difference of the range of the tide at different places on the Earth's surface. If the surface of our globe were entirely covered with water, the height of a solar tide would be 1 ft. $11\frac{1}{30}$ in., and of a lunar tide 4 ft. 0 in.; but the differences in the level of the water of the ocean brought about by tidal influences are often far in excess of these figures; for instance, in deep estuaries or creeks, open in the direction of the tidal wave, and gradually converging inward, the range is very much greater than elsewhere, as at—

	Feet.
Bristol Channel (off Chepstow)	70
Bay of Fundy	60
Gallegos River (Patagonia)	46
Mouth of the Avon	42
St. Malo	40
Bristol	40
Milford Haven	36

On the other hand, where promontories or headlands jut out into the sea, the tidal range is frequently small; thus:—

	Feet.
Wicklow	4
Weymouth	7
The Needles	9
Cape Clear	11

In very large open tracts of water, like the Atlantic or the Pacific Oceans, and in narrow confined seas, like the Baltic, the Mediterranean, &c., the elevation of the tidal wave is often very inconsiderable; thus:—

	Feet.	Inches.
Toulon	1	0
Antium	1	2
Porto Rico (S. Juan)	1	6
South Pacific	1	8
St. Helena	3	0

The usual range of the tides at any particular place is also affected by certain conditions of the atmosphere. At Brest, a depression of 1 inch in the barometric column causes a difference of 16 in. in the elevation of the high-water mark; at Liverpool, corresponding to the depression of 1 in., the difference is about 10 in.; and at the London Docks about 7 in.: thus when the barometer is low, an unusually high tide may be expected, and *vice versâ.* And the influence of the wind also is frequently very considerable, so much so that during a violent hurricane, Jan. 8, 1839, there was no tide at all at Gainsborough on the river Trent, a circumstance never before recorded. Smeaton found experimentally in a canal 4 miles long, that the water-level at one end was 4 inches higher than at the other, owing to the force of the wind acting on the surface of the water.

The tides in the Pacific Ocean present great anomalies. The following remarks respecting them are by a missionary:—

"It is, to the missionaries, a well-known fact that the tides in Tahiti and the Society Islands are uniform throughout the year, both as to the time of the ebb and flow, and the height of the rise and fall, it being high water invariably at noon and at midnight, and consequently the water is at its lowest point at 6 o'clock in the morning and evening. The rise is seldom more than 18 inches or 2 feet above low-water mark. It must be observed that mostly once, and frequently twice in the year, a very heavy sea rolls over the reef, and bursts with great violence upon the shore. But the most remarkable feature in the periodically high sea is, that it invariably comes from the W. or S.W., which is the opposite direction to that

from which the Trade wind blows. The eastern sides of the island are, I believe, never injured by these periodical inundations. I have been thus particular in my observations, for the purpose in the first place of calling the attention of scientific men to this remarkable phenomenon, as I believe it is restricted to the Tahitian and Society Island Groups in the South Pacific, and the Sandwich Islands in the North. I cannot, however, speak positively respecting the tides at the islands eastward of Tahiti; but all the islands I have visited in the same parallel of longitude southwards, and in those to the westward in the same parallel of latitude, the same regularity is *not* observed, but the tides vary with the Moon, both as to the time and the height of the rise and fall, which is the case at Raratonga[a]."

The late Admiral Beechey is, so far as I know, the only person who ever attempted any solution of the question, and he proposed as a simile, a basin to represent the harbour, over the margin of which the sea breaks with considerable violence, thereby throwing in a larger body of water than the narrow channels can carry off in the same time, and consequently the tide rises, and as the wind abates the water subsides.

The writer above quoted objects to this explanation, and he brings forward several arguments, and states several facts, of which the following is an abstract:—

1. The undeviating regularity of the tide is so well understood by the natives that they distinguish the hours of the day by terms descriptive of the state of the tide, such as the following: "Where is the tide?" instead of, as we should say, "What o'clock is it?"

2. There are many days during the year when it is perfectly calm, and yet the tide rises and falls in the same way, and very frequently there are higher tides in calms than during the prevalence of the Trade wind.

3. The tides are as regular on the West side of the island, where the Trade wind does not reach, as on the East, from which point it blows.

4. The Trade wind is most powerful from noon till 4 or 5 o'clock p.m., during which time the water ebbs so fast that it reaches its lowest level by 6 o'clock p.m., instead of in the morning, as Admiral Beechey states, at which time it is again high water.

Admiral Beechey's explanation does not seem very satisfactory, but we are not yet in possession of any other.

The velocity of the tidal wave is subject to much variation, and

[a] J. Williams, *Narrative of Missionary Enterprises in the South Seas*, p. 201.

we are not yet in a position to lay down the laws which govern it; if the whole globe were uniformly covered, the velocity would be rather more than 1000 miles per hour ($7926 \times 3{\cdot}1416 \div 24{\cdot}8$). It is probably, however, nowhere equal to this, unless perhaps in the Antarctic Ocean. The following table of velocities is given by Whewell[b]:—

	Miles.
In latitude 60° S.	670
In the Atlantic	700
Azores to Cape Clear	500
Cape Clear to Duncansby Head	160
Buchan Ness to Sunderland	60
Scarborough to Cromer	35
North Foreland to London	30
London to Richmond	13

Concerning the general character of the great terrestrial tidal wave, I cannot do better than quote the following description by a well-known eminent geographer:—

"The Antarctic is the cradle of tides. It is here that the Sun and Moon have presided over their birth, and it is here, also, that they are, so to speak, to attend on the guidance of their own congenital tendencies. The luminaries continue to travel round the Earth (apparently) from East to West. The tides no longer follow them. The Atlantic, for example, opens to them a long, deep canal, running from North to South, and after the great tidal elevation has entered the mouth of this Atlantic canal, it moves continually Northward; for the second 12 hours of its life it travels north from the Cape of Good Hope and Cape Horn, and at the end of the first 24 hours of its existence, has brought high water to Cape Blanco on the West of Africa, and Newfoundland on the American continent. Turning now round to the Eastward, and at right angles to its original direction, this great tidal wave brings high water, during the morning of the 2nd day, to the Western coasts of Ireland and England. Passing round the Northern cape of Scotland, it reaches Aberdeen at noon, bringing high water also to the opposite coasts of Norway and Denmark. It has now been travelling precisely in the opposite direction to that of its genesis, and in the opposite direction, also, to the relative motion of the Sun and Moon. But its erratic course is not yet complete. It is now travelling from the Northern mouth of the German Ocean Southwards. At midnight of the 2nd day it is at the mouth of the Thames, and wafts the merchandise of the world to the quays of the port of London. In the course of this rapid journey the reader will have noticed how the lines [on the map] in some parts are crowded together closely on each other, while in others they are wide asunder. This indicates that the tide-wave is travelling with varying velocity. Across the southern ocean it seems to travel nearly 1000 miles an hour, and through the Atlantic scarcely less; but near some of the shores, as on the coast of India, as on the East of Cape Horn, as round the shores of Great Britain, it travels very slowly; so that it takes more time to go from Aberdeen to London

[b] *Phil. Trans.*, vol. cxxiii. p. 212. 1833.

than over the arc of 120° which reaches from 60° of Southern latitude to 60° North of the Equator. These differences have still to be accounted for; and the high velocities are invariably found to exist where the water is deep, while the low velocities occur in shallow water. We must therefore look to the conformation of the shores and bottom of the sea as an important element in the phenomena of the tides[c]."

The effects of tides on rivers are often very striking; especially is this the case with the Avon at Bristol: when the tide is at its ebb, the river is little better than a shallow ditch, but when the waters have risen to the maximum height, an insignificant stream is converted into a broad and deep channel, navigable by the largest Indiaman.

The instinct of animals in respect of the tides is often very remarkable. A Scotch writer observes: "The accuracy with which cattle calculate the times of ebb and flow, and follow the diurnal variations, is such, that they are seldom mistaken, even when they have many miles to walk to the beach. In the same way they always secure their retreat from these insulated spots in such a manner that they are never surprised and drowned[d]."

In their passage up rivers, tides are gradually extinguished, as will be seen from the following table relating to the Thames[e]:—

	Height.		Distance from Mouth.
London (Docks)	18 ft.	10 in.	.. 60 m.
Putney	10	2	.. 67½
Kew	7	1	.. 73
Richmond	3	10	.. 76
Teddington	1	4½	.. 79

At certain places on the coast of Hampshire and Dorsetshire the waters of the ocean ebb and flow *twice* in 12 hours instead of only once, as is usual elsewhere. Southampton, Christchurch, Poole, Weymouth, and the Firth of Forth, may be mentioned as places where this singular phenomenon has been observed[f].

Another abnormal tidal phenomenon, presenting some remarkable features, occurs once a year in the rivers Severn, Humber[g], and Loire, and in some other rivers[h] of the same character as regards the formation of their banks. This is the "hygre," or "bore," and is due to the fact that a wide estuary at the mouth of the river

c Johnston, *Phys. Atlas.*

d Mac Culloch, *Highlands and Western Isles of Scotland.*

e *Phil. Trans.*, vol. cxxiii. p. 204. 1833.

f *Phil. Trans.*, vol. cxxiii. p. 226. 1833.

g White, *Eastern England*, vol. ii. ch. 3.

h The river Dordogne in France is occasionally the scene of a natural phenomenon which would appear to present some analogy to the Bore of the Severn.

suddenly contracts like a funnel. The result is, that the estual spring tide rushes up with an overpowering force, carrying all before it. This further peculiarity likewise subsists: namely, that there is no "slack-water," as is ordinarily the case in other rivers, between the ebb and flow of the tide. The approach of the bore on the Severn may be heard at a considerable distance roaring, as it were, in its upward progress. The head is about 3 feet high, and it frequently does a good deal of mischief to property. The maximum effect is at the 4th tide after the Full Moon.

The evident connexion between the periods of the tides and those of the phases of the Moon led to the tides being attributed to the Moon's action long before their true theory was understood. Aristotle[i] and Pytheas of Marseilles[k] are both said to have pointed out the connexion. Julius Cæsar adverts to the connexion existing between the Moon and spring tides[l].

Pliny says: "Æstus maris accedere et reciprocare, maxime mirum: pluribus quidem modis: *verum causa in sole lunâque*[m]." Kepler clearly indicated that the principle of gravitation is concerned[n] — an opinion from which Galileo strongly dissented[o]. Wallis, in 1666, also published a tidal theory[p]. Before Sir Isaac Newton turned his attention to this subject, the explanations given were at best but vague surmises. "To him was reserved the glory of discovering the true theory of these most remarkable phenomena, and of tracing, in all its details, the operation of the cause which produces them."

[i] Περὶ Κόσμου.
[k] Plutarch, *De Placitis*, lib. iii. cap. 17.
[l] *De Bello Gallico*, lib. iv. cap. 29.
[m] Pliny, *Hist. Nat.*, lib. ii. cap. 99.
[n] *Epist. Ast.*, p. 555.
[o] *Dialoghi.*
[p] *Phil. Trans.*, vol. i. p. 263. 1666.

CHAPTER III.

PHYSICAL PHENOMENA.

Secular Variation in the Obliquity of the Ecliptic.—Precession.—Its value.—Its physical cause.—Correction for Precession.—History of its discovery.—Nutation.—Herschel's definition of it.—Connexion between Precession and Nutation.

SECULAR Variation in the Obliquity of the Ecliptic.—Although it is sufficiently near for most purposes to consider the inclination of the plane of the ecliptic to that of the equator as invariable, yet this is not strictly the case, inasmuch as it is subject to a small but appreciable change of 46·45″ (C. A. F. Peters) per century. This phenomenon has long been known to astronomers, on account of the increase it causes in the latitude of all stars in some situations, and corresponding decrease in the opposite regions. Its effect at the present time is to diminish the inclination of the two planes of the equator and the ecliptic to each other; but this diminution will not go on[a] beyond certain very moderate limits, after which it will again increase, and thus oscillate backwards and forwards through an arc of 1° 21′: the time occupied in one oscillation being about 10,000 years. One effect of this variation of the plane of the ecliptic—that which causes its nodes on a fixed plane to change—is associated with the phenomena of the precession of the equinoxes, and cannot be distinguished from it, except in theory[b].

Precession.—The precession of the equinoxes is a slow but con-

[a] Compare *Genesis* viii. 22.

[b] The inclination of the ecliptic for the epoch of January 1, 1878, is 23° 27′ 18·50″.

tinual shifting of the equinoctial points from East to West[c]. Celestial longitudes and right ascensions are reckoned from the vernal equinox, and if this were a fixed point, the longitude of a star would never vary, but would remain the same from age to age as does its latitude (*sensibly*). Such, however, is not the case; as it has been found that *apparently* all the stars have changed their places since the first observations were made by the astronomers of antiquity[d]. Two explanations only can be given to account for this phenomenon: we must either suppose that the whole firmament has advanced, or that the equinoctial points have receded. And as these points depend on the Earth's motion, it is far more reasonable to suppose that the phenomenon is owing to some perturbation of our globe rather than that the starry heavens should have a real motion relative to these points. The latter explanation is accordingly adopted, namely, that the equinoxes have a periodical retrograde motion from *East* to *West*, thereby causing the Sun to arrive at them sooner than it otherwise would had these points remained stationary. The annual amount of this motion is, however, exceedingly small, being only equal to $50{\cdot}2''$[e]; and since the circle of the ecliptic is divided into 360°, it follows that the time occupied by the equinoctial points in making a complete revolution of the heavens is 25,817 years. It is owing to precession that the Pole-star varies from age to age, and also that whilst the sidereal year, or *actual* revolution of the Earth round the Sun, is $365^d\ 6^h\ 9^m\ 11{\cdot}0^s$, the equinoctial, solar, or tropical year is only $365^d\ 5^h\ 48^m\ 46{\cdot}05^s$ (Airy). The successive

[c] It may be well to mention that the equinoxes are the two points where the ecliptic cuts the equator; and so called because when the Sun in its annual course arrives at either of them, day and night are equal throughout the world. The point where the Sun crosses the equator, going north, is known as the *vernal equinox*; and the opposite point, through which the Sun passes going south, as the *autumnal equinox*. These intersecting points are also termed nodes, and an imaginary line joining the two, *the line of nodes*. The ascending node (☊) answers to the vernal equinox, and the descending (☋) to the autumnal.

[d] By "change of place" is here meant change of position of the Sphere as a whole to certain fixed co-ordinates, not change of place of the Stars *inter se*, so as to alter the figures of the Constellations; although many individual stars—as we shall see hereafter—have very considerable proper motions.

[e] Bessel, by a careful discussion of the most reliable observations, fixed the value of general precession for the epoch of 1750 at $50{\cdot}21129''$, and the value of luni-solar precession at $50{\cdot}37572''$. For the epoch of 1800 he gave for the value of the latter $50{\cdot}36354''$. The lunar precession is about $2\frac{1}{2}$ times the solar precession, just as the lunar tide is $2\frac{1}{2}$ times the solar tide, and for much the same reason, namely, the difference of the attractions.

returns of the Sun to the same equinoctial points must therefore precede its return to the same point on the ecliptic by $20^m\ 24{\cdot}95^s$ of time, which corresponds to about $50{\cdot}27''$ of arc. It is also on account of the precession of the equinoxes that the signs of the ecliptic do not now correspond with the constellations of the same name, but lie about 28° Westward of them. Thus, that division of the ecliptic known as the *sign* of Taurus lies in the *constellation* Aries, the sign of Aries having passed into Pisces. It should be remarked, however, that the signs and constellations coincided with one another about 100 B.C. In recent times, the attempts that have been made to establish the motion of the solar system through space have rendered an accurate knowledge of precession indispensable; and the elaborate researches of C. A. F. Peters and W. Struve have led to a slight modification in the value of the constants of precession adopted by Bessel [f], which may lead to important results.

"The cause of precession is to be found in the combined action of the Sun and Moon [g] upon the protuberant mass of matter accumulated at the Earth's equator, the attraction of the planets being scarcely sensible [h]. The attracting force of the Sun and Moon upon this shell of matter is of a two-fold character; one parallel to the equator, and the other perpendicular to it. The tendency of the latter force is to diminish the angle which the plane of the equator makes with the ecliptic; and were it not for the rotatory motion of the Earth, the planes would soon coincide; but, by this motion, the planes remain nearly constant to each other. The effect produced by the action of the force in question is, however, that the plane of the equator is constantly, though slowly, shifting its place in the manner we have endeavoured to describe."

In the reduction of astronomical observations the correction to be applied for precession in right ascension is almost always additive; increasing in the regions round the poles of the heavens, but becoming very small near the poles of the ecliptic. It is in the space included between these poles in each hemisphere that the correction becomes subtractive; in the northern hemisphere, this

[f] *Tabulæ Regiomontanæ.*

[g] Called hence, *luni-solar* precession.

[h] When the value of the constant of precession, given at any time, includes the variation caused by the planets, it is called the constant of *general* precession.

small space comprehends the constellations lying near the XVIIIth hour of R.A., that being the R.A. of the North ecliptic pole; and in the southern hemisphere, the constellations lying near the VIth hour, that being the R.A. of the South ecliptic pole. The remarks I have just made apply only to those stars whose declination North or South exceeds 67°. The annual precession in declination, however, depends on the star's right ascension only, both as to amount and direction. At VI and XVIII hours it is at zero; at XII hours it reaches the Northern maximum of 20″; and at XXIV it reaches a similar Southern maximum. From XVIII to XXIV hours, and from XXIV to VI hours, the precession is N., consequently additive to stars of North declination, but subtractive from those of South declination: but from VI to XVIII, the precession being S., it is additive to Southern, and subtractive from Northern stars.

The discovery of precession dates from about 125 B.C., when it was detected by Hipparchus, by means of a comparison of his own observations with those of Timocharis and Aristyllus, made about 178 years previously: its existence was afterwards confirmed by Ptolemy[i]. It was Copernicus, however, who first gave the true explanation of the phenomenon, and Newton who discovered its physical cause.

Nutation[k].—It must be borne in mind that the effect of precession varies according to the time of year, on account of the ever-varying distance of the Earth from the Sun. Twice a year, (at the equinoxes,) the influence of the Sun is at zero; and twice a year also, (at the solstices,) it is at its maximum. On no two successive days is it of exactly the same value, and consequently the precession of the equinoctial points is uneven, and the obliquity of the ecliptic is subject to a half-yearly variation; since the Sun's force which changes the obliquity is constantly varying, while the rotation of the Earth is continuous. This then gives rise to a small oscillating motion of the Earth's axis, termed the *solar nutation:* of a far more considerable amount, however, is the value of the nutation arising from the agency of the Moon; so much so that it was detected by Bradley before even its existence had been inferred from theory[l].

[i] *Almagest*, lib. vii.

[k] *Nutatio*, nodding.

[l] *Phil. Trans.*, vol. xlv. p. 1. 1748.

The nature of nutation cannot be better explained than in nearly the words of Sir J. Herschel, who says:—"The nutation of the Earth's axis is a small and slow gyratory movement, by which, if subsisting alone, the pole would describe among the stars, in a period of 18⅔ years, a minute ellipse having its longer axis equal to 18·5″, and its shorter to 13·74″ (the longer being directed towards the pole of the ecliptic, and the shorter of course at right angles to it); the semi-axis major is, therefore, equal to 9·25″, which quantity is called the '*coefficient of nutation* [m].' The consequence of this real motion of the pole is an apparent advance and recess of all the stars in the heavens to the pole in the same period. Since, also, the place of the equinox on the ecliptic is determined by the place of the pole in the heavens, the same agency will cause a small alternating motion to and fro of the equinoctial points, by which, in the same periods, both the longitudes and the right ascensions of the stars will be alternately increased and diminished.

"Precession and nutation, although for convenience here considered separately, in reality exist together; they are, in fact, constituent parts of the same general phenomenon: and since, while in virtue of this nutation, the pole is describing its little ellipse of 18·5″ in diameter, it is carried on by the greater and regularly progressive motion of precession over so much of its circle round the pole of the ecliptic as corresponds to 18⅔ years—that is to say, over an angle 18⅔ times 50·1″ round the centre (which, in a small circle of 23° 28′ in diameter, corresponds to 6′ 20″, as seen from the centre of the sphere); the path which it will pursue in virtue of the joint influence of the 2 motions will be neither an ellipse nor an exact circle, but a slightly undulating ring.

"These movements of precession and nutation are common to all the celestial bodies, both fixed and erratic; and this circumstance makes it impossible to attribute them to any other cause than the real motion of the Earth's axis, as we have described. Did they only affect the stars, they might, with equal plausibility, be considered as arising from a *real* rotation of the starry heavens as a solid shell round our axis, passing through the poles of the

[m] Other values are: Busch's 9·2320″, Lundahl's 9·2361″, C. A. F. Peters's 9·2164″. A mean of these, namely 9·2231″, is the value finally adopted by Peters. (*Numerus constans Nutationis*, 4to. Petropoli, 1842: see p. 5 of W. Struve's *Rapport* on Peters's Memoir.

ecliptic in 25,868 years, and a real elliptic gyration of *that* axis in rather more than 18 years: but since they also affect the Sun, Moon, and planets, which, having motions independent of the general body of the stars, cannot without extravagance be supposed to be *attached to* the celestial conclave, this idea falls to the ground; and there only remains, then, a real motion of the Earth by which they can be accounted for [n]."

[n] *Treatise on Ast.*, p. 172. 1833. In his *Outlines of Astronomy* Sir John altered this statement of nutation, but the original version strikes me as being the better of the two, and therefore I retain it here.

CHAPTER IV.

OPTICAL-ILLUSION PHENOMENA.

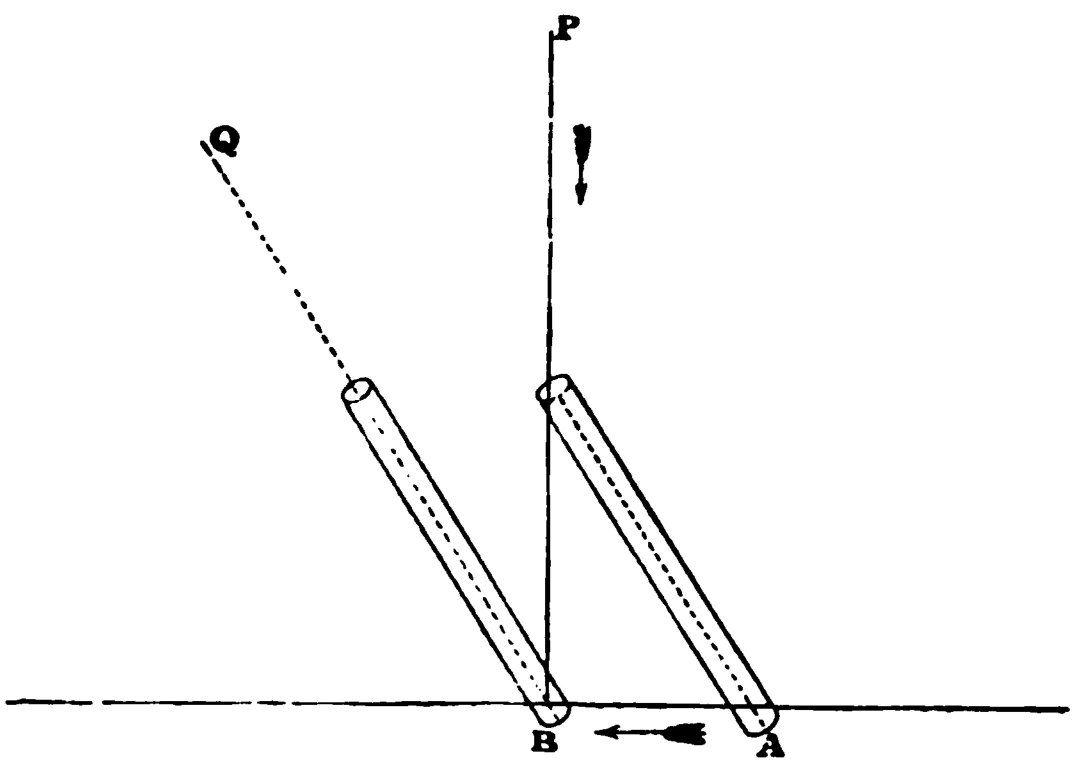
Aberration.—The constant of Aberration.—Familiar illustration.—History of the circumstances which led to its discovery by Bradley.—Parallax.—Explanation of its nature.—Parallax of the heavenly bodies.—Parallax of the Moon.—Importance of a correct determination of the Parallax of an object.—Leonard Digges on the distance of the Planets from the Earth.

ABERRATION.—The aberration of light is another important phenomenon which requires to be taken into consideration in the reduction of astronomical observations. Although light travels with the enormous velocity of 186,660[a] miles per second —a speed so great, that for all practical terrestrial purposes we may consider it to be propagated instantaneously; yet the astronomer, who has to deal with distances of millions of miles, is obliged to be more precise. A simple illustration will shew this: if we take the mean distance of our globe from the Sun at 91,435,000 miles, and consider that light travels at the rate of 186,660 miles per second, we may ascertain by a mere arithmetical process that the time occupied by a ray of light in reaching us from the Sun is $8^m\ 9{\cdot}8^s$, so that in point of fact, in looking at the Sun at a given moment, we do not see it shining as it is, but as it was $8^m\ 9{\cdot}8^s$ previously. If the Earth were at rest, this would be a trivial matter; but as the Earth is in motion, it follows that when the solar ray enters the eye of a person on its surface, he will be some way removed from the point in space at which he was situated when the ray left the Sun; he will consequently see that luminary behind the true place it actually occupies when the ray enters his

[a] A. Cornu, *Proceedings of the Roy. Inst.*, vol. vii. p. 472. May 1875.

eye. In the course of $8^m\ 9{\cdot}8^s$ the Earth will have advanced in its orbit 20·1156″; this quantity is called the *constant of aberration* [b]. Aberration may be defined to be a phenomenon resulting from the combined effect of the motion of light and of the motion of the Earth in its orbit [c]. Suppose a ball let fall from a point P above the horizontal line AB, and a tube, of which A is the lower extremity, placed to receive it; if the tube were fixed the ball would strike it on the lower side, but if the tube were carried forwards in the direction AB, with a velocity properly adjusted at every instant to that of the ball while *preserving its inclination* to the horizon, so that when the ball in its natural descent reached B the tube would

Fig. 94.



ABERRATION.

have been carried into the position BQ, it is evident that the ball throughout its whole descent would be in the tube; and a spectator referring to the tube the motion of the ball, and carried along with the former, unconscious of its motion, would fancy that the ball had been moving in an inclined direction and had come from Q. The following similes are frequently used to exemplify aberration: a shower of rain descending perpendicularly will appear to fall in its true direction to a person at rest, but if he move rapidly through it, it will meet him in a slanting direction: in

[b] Baily's value is 20·4192″; W. Struve's is 20·4451″; C. A. F. Peters's, 20·4255″, 20·503″, and 20·481″; Lindenau's, 20·4486″; and Lundahl's, 20·5508″. Struve's has hitherto been considered the best.

[c] See a paper by Challis in *Phil. Mag.*, 4th ser., vol. ix. p. 430. June 1855.

other words, it will have an apparent as well as a real motion. A cannon-ball fired from a shore-battery at a vessel passing up a river will not pass through the ship in a line coincident with the direction of the ball, but will emerge on the other side at a point differing more or less from this line; the amount of the variation, however, will depend on the relative velocities of the ball and ship at the time. If we suppose the cannon-ball to represent light, and the movement of the ship the motion of the Earth in its orbit, we have an excellent illustration of the phenomenon of aberration [d].

This unquestionably grand discovery resulted more immediately from an attempt to detect stellar parallax. Although the facts revealed by the invention of the telescope and the discovery of gravitation had the effect of establishing beyond doubt the truth of the Copernican theory of the universe, still it was much to be desired that some more *direct* proof should be adduced. The absence of any appreciable change in the positions of the fixed stars when examined from opposite sides of the Earth's orbit, was one of the earliest, and at the same time one of the most serious, arguments brought against the system of Copernicus; as it was always considered that the detection of such a change would furnish an irresistible proof that the Earth was not at rest, and consequently was not the centre of the system. The first observation which ultimately led to the discovery of aberration was made by Hooke, who selected the star γ Draconis as suitable for the detection of annual parallax [e]. After observing it carefully at different seasons of the year, he came to the conclusion that it had a sensible parallax. It was soon found, however, that the star was subject to a displacement in a direction contrary to that which ought to have resulted had the star been affected by parallax only; and it was for the purpose of endeavouring to ascertain the physical cause of this strange phenomenon that Bradley was led to provide himself with an instrument, that he might more conveniently study the subject of parallax and anything that might arise connected therewith.

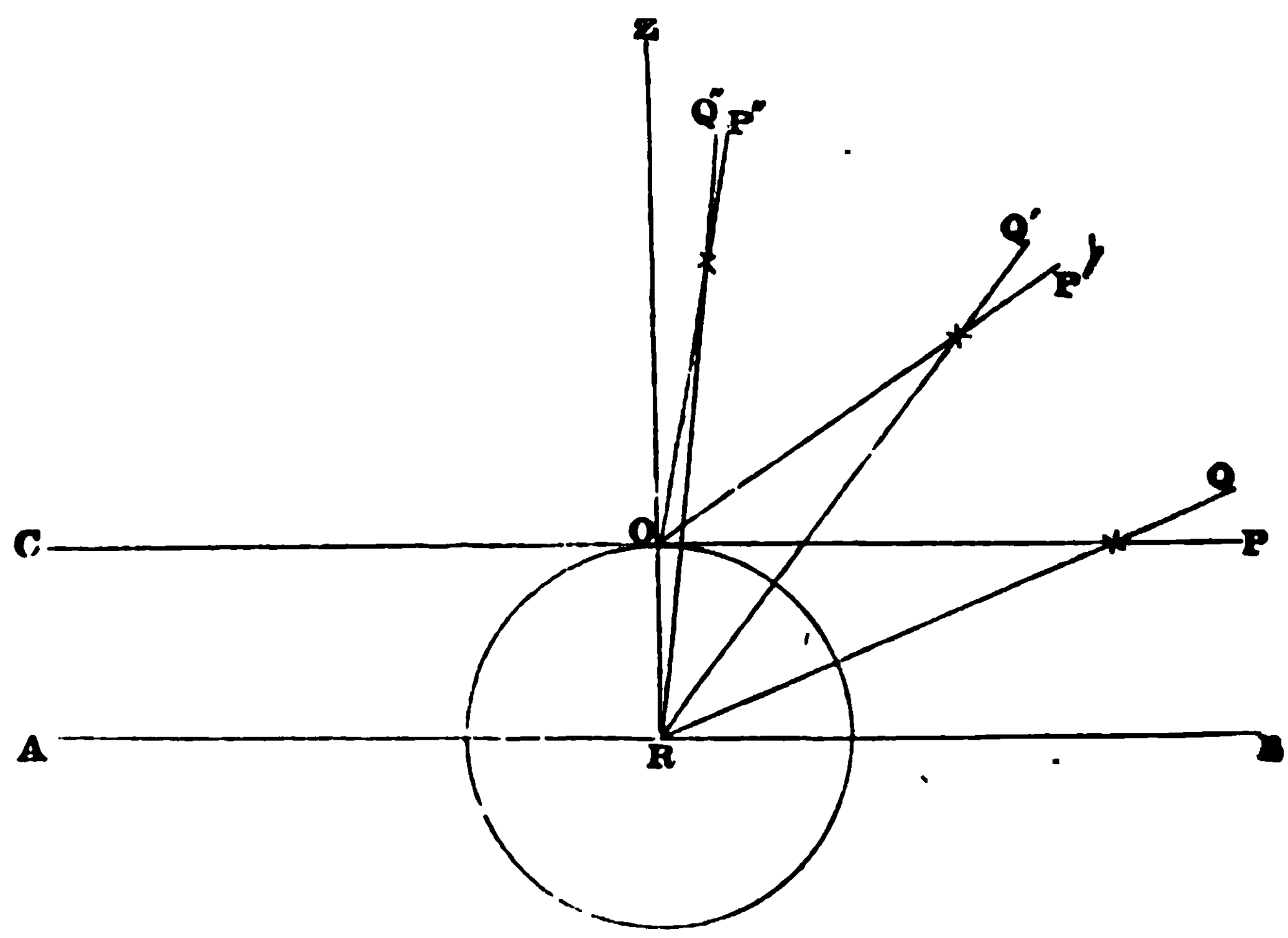
[d] See Airy's *Lectures on Astronomy*, p. 188.

[e] Hooke considered it desirable to observe stars as near the zenith as possible, in order to avoid the effects arising from any uncertainty as to the value of refraction; and γ Draconis happened to be the only bright star passing within a few minutes of the zenith of Gresham College, where his instrument was erected. (*Attempt to prove the Motion of the Earth*, p. 7.)

His observations completely confirmed those of Hooke, and "at length the happy idea occurred to him, that the phenomenon might be completely accounted for by the gradual propagation of light combined with the motion of the Earth in its orbit."

Parallax "is the apparent change of place which bodies undergo by being viewed from different points." This is the general signification of the word; but with the astronomer it has a conventional meaning, and implies the difference between the apparent positions of any celestial object when viewed from the surface of the Earth and from the centre of either the Earth or the Sun, to one or other

Fig. 95.



Parallax.

of which centres it is usual to refer all astronomical observations. The position of a heavenly body, as seen from the Earth's surface, is called its *apparent place;* and that in which it would be seen, were the observer stationed at the Earth's centre, is known as the *true place.* It is plain, therefore, that the altitudes of the heavenly bodies are depressed by parallax, which is greatest at the horizon [f], and decreases as the altitude of the object increases, until it disappears altogether at the zenith. In figure 95, Z is the zenith,

[f] This is the case because imaginary lines, drawn from the object to the observer, and to the centre of the Earth respectively, will then have the greatest possible inclination to each other.

C P the visible horizon, A B the rational horizon, O the position of an observer, and R the centre of the Earth. From O the observer will see the stars projected on the sky at P, P′, and P″, (*apparent places*); but, referred to the centre of the Earth, the points of projection will be Q, Q′, and Q″ (*geocentric places*). The general nature of parallax may be readily understood by supposing 2 persons placed each at the end of a straight line, to look at a carriage standing in front of a house at the distance (say) of 50 yards from each station. It is evident that the carriage will appear to each spectator projected upon different parts of the house. The angle which this difference of position gives rise to, that is to say the angle formed by the 2 lines of direction, is the angle of parallax. Let us suppose the 2 observers (still at the same distance from each other) to recede from the carriage; the angle of parallax will become more and more acute, until at length it will become insensible. The example here adduced may be applied to the heavenly bodies. The Sun, Moon, and planets, though separated from us by millions of miles, are affected by parallax to a small but nevertheless appreciable amount. With but a few exceptions, however, this is not the case with the fixed stars; for in only about a dozen instances has parallax been detected, and, so far as is yet known, the star *nearest* to us is *a* Centauri, whose parallax is equal to only 0·918″, which is equivalent to 20,527,000,000,000 miles, as will appear hereafter[g].

Of all the heavenly bodies, the Moon is that of which the horizontal parallax is the most considerable, because that luminary is the nearest to the Earth. It is found in the following way:—Suppose that 2 astronomers take their stations on the same meridian, one South of the equator, as at the Cape of Good Hope, and the other North of the equator, as at Berlin, which 2 places lie nearly on the same meridian: the observers would severally refer the Moon to different points on the face of the sky—the Southern observer carrying it farther to the North, and the Northern observer farther to the South, than its true place as seen from the centre of the Earth. The observations thus made at the 2 places furnish

[g] As illustrating the delicacy of observations of this kind, the following remark of Airy's is instructive. "An angle of 2″ is that in which a circle $\frac{6}{10}$ of an inch in diameter would be seen at the distance of a mile. This is [that of] the star which shews the *greatest parallax of all.*" *Lectures on Ast.*, p. 196.

the materials for calculating, by means of trigonometry, the value of the horizontal parallax of the Moon, from which we can deduce both its distance and real magnitude. The parallax thus obtained is called the *diurnal*, or geocentric, a term used to distinguish such parallax from *annual*, or heliocentric, parallax. And in general it may be stated that these terms express the angular displacement of a celestial object according as it is viewed from the Earth or the Sun respectively: in particular, however, it denotes the angle formed by 2 imaginary lines drawn from each extremity of the diameter of the Earth's orbit to a fixed star. But, as before stated, this angle is generally too small to be appreciable. It was this fact of the non-detection of annual parallax which for a long period of time prior to the invention of the telescope formed a great obstacle to the progress of the Copernican opinions relative to the system of the universe.

We may obtain some idea of the importance attaching to a correct determination of the parallax of an object by an inspection of the following table :—

If the Sun's horizontal parallax were 11″, the mean distance of the following planets from the Sun in miles would be :—

The Earth.	*Mars.*	*Jupiter.*	*Saturn.*
75,000,000	114,276,750	390,034,500	715,504,500
If the Sun's parallax were 10″, the above distance would become :—			
82,000,000	124,942,580	426,478,720	782,284,920
Errors arising from a mistake of only 1″ :—			
7,000,000	10,665,830	36,444,220	66,780,420[h]
If the Sun's true parallax be taken at 8·94, the real distances will be :—			
91,435,000	139,311,000	475,695,000	872,142,000

It is only within comparatively the last few years that the efforts of astronomers to detect stellar parallax have been attended with any amount of success. The discovery of planetary parallax is of course of older date. Pliny considered such investigations to be but little better than madness, and Riccioli remarks, "Parallaxis et distantia stellarum fixarum, non potest certa et evidenti observatione humanitùs comprehendi." Leonard Digges, an old English writer, however, seems to have found no difficulty in the matter; he gives the following table of distances, which, however,

[h] Ferguson's *Astronomy*, p. 76. 2nd Edition, London, 1757.

unfortunately for his reputation, has turned out to be seriously incorrect. He adds, "Here demonstracion might be made of the distaunce of these orbes, but that passeth the capacity of the common sort." These are his results[1]:—

	Myles.
"From the Earth to the Moone	15,750
From the Moone to Mercury	12,812
From Mercury to Venus	12,812
From Venus to the Sunne	23,437½
From the Sunne to Mars	15,725
From Mars to Jupiter	78,721
From Jupiter to Saturne	78,721
From Saturne to the Firmament	120,485."

Whence it follows, according to Digges, that the distance from London to the stars is exactly 358,463½ miles!

[1] *Prognostication Euerlastinge*, 2nd ed. 1576, fol. 16.

CHAPTER V.

Refraction.—Its nature.—Importance of a correct knowledge of its amount.—Table of the correction for refraction.—Effect of refraction on the position of objects in the horizon.—History of its discovery.—Twilight.—How caused.—Its duration.

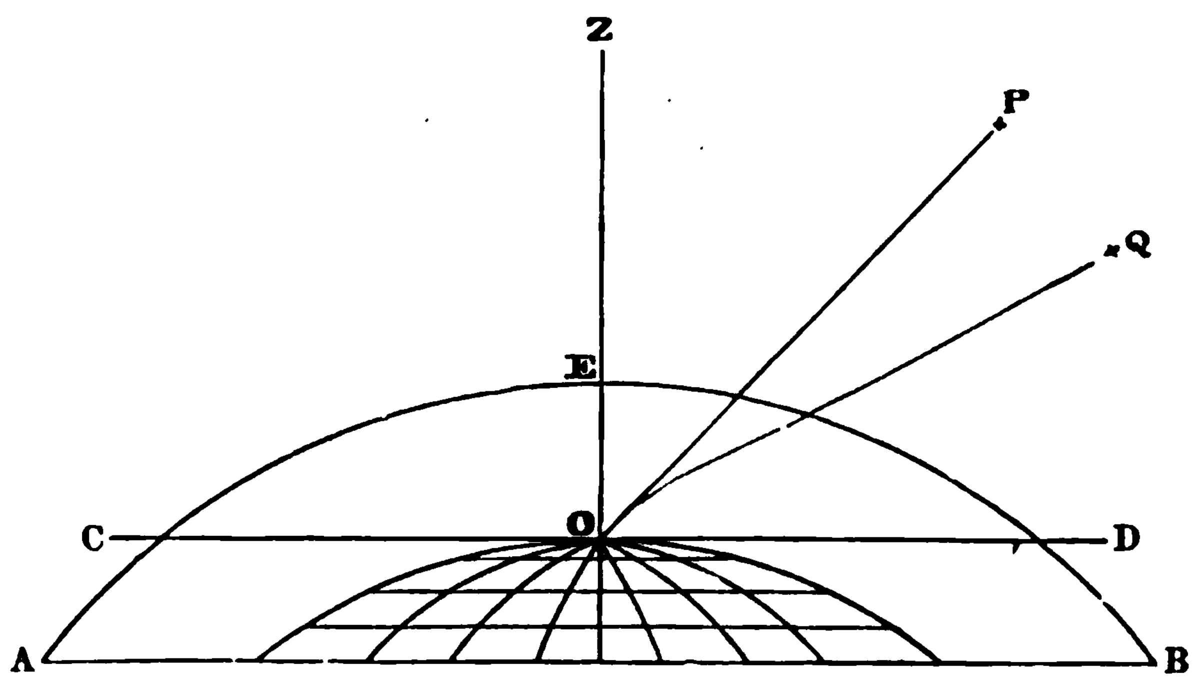
REFRACTION.—Besides the change of place to which the heavenly bodies are subjected by the effects of parallax, atmospheric refraction gives rise to a considerable displacement; and it is this power which the air, in common with all transparent media, possesses, which renders a knowledge of the constitution of the atmosphere a matter of importance to the astronomer. "In order to understand the nature of refraction, we must consider that an object always appears in the direction in which the *last* ray of light comes to the eye. If the light which comes from a star were bent into 50 directions before it reached the eye, the star would nevertheless appear in a line described by the ray nearest the eye. The operation of this principle is seen when an oar, or any stick, is thrust into the water. As the rays of light by which the oar is seen have their direction changed as they pass out of water into air, the apparent direction in which the body is seen is changed in the same degree, giving it a bent appearance—the part below the water having apparently a different direction from the part above[a]."

The direction of this refraction is determined by a general law in optics, that when a ray of light passes out of a rarer into a denser medium—*e.g.* out of air into water, or out of space into the Earth's atmosphere—it is bent *towards* a perpendicular to the

[a] Olmsted, *Mechanism of the Heavens*, p. 94. Edinburgh edition. In Sir J. Herschel's *Outlines of Ast.* (pp. 27 *et seq.*) there will be found a useful summary of information concerning refraction.

surface of the medium; but when it passes out of a denser into a rarer medium, it is bent *from* the perpendicular. Inasmuch then as we see any object in the direction in which the rays emanating from it reach the eye, it follows that the effect of refraction is to make the apparent altitude of a heavenly body appear greater than the true altitude; so that for example any object situated actually *in* the horizon will appear *above* it. Indeed, some objects that are actually below the horizon, and which would be otherwise invisible were it not for refraction, are thus brought into sight. It was in consequence of this that on April 20, 1837, the Moon rose eclipsed before the Sun had set; and other like instances are on record.

Fig. 96.



REFRACTION.

In fig. 96, Z is the zenith, C D the visible horizon, A B a parallel of latitude, A E B the boundary of the Earth's atmosphere. Then the light of the star Q will, to the observer at O, seem to come from the point P.

A correct determination of the exact amount of atmospheric refraction, or the angular displacement of a celestial object at any altitude, is a very important, but a very difficult subject of inquiry, owing to the fact that the density of any stratum of air (on which its refractive power depends) is affected by the operation of meteorological phenomena with which we are at present but very imperfectly acquainted. Thus the amount of refraction at any given altitude depends not only on the density but also on the thermometric and hygrometric conditions of the air through which the visual ray passes. And although we know the general fact

that the barometric pressure[b] and the temperature[c] constantly diminish as we rise from the Earth's surface, yet the law of this diminution is not fully ascertained. In consequence of our ignorance on these points, some degree of uncertainty is introduced into the determination of the amount of refraction, which affects astronomical observations involving extremely minute quantities. Nevertheless it must be remembered that inasmuch as the total amount of refraction is never considerable, and in most cases very small, it can be so nearly estimated as to offer no serious impediment to the astronomer.

Tables are in use[d], constructed partly from observation, and partly from theory, by means of which we can ascertain approximately the mean refraction at any given altitude; additional rules being given by which this average refraction may be corrected according to the state of the air at the time of observation. At the zenith, or at an altitude of 90°, there is no refraction whatever, objects being seen in the position which they would have were the Earth devoid of any atmosphere at all. In descending from the zenith towards the horizon, the refraction constantly increases, objects near the horizon being displaced in a greater degree than those at high altitudes. Thus the refraction, which at an altitude of 45° is only equal to 57″, at the horizon increases to no less than 35′. The rate of the increase at high altitudes is nearly in proportion to the tangent of the apparent angular distance of the object from the zenith; but in the vicinity of the horizon this rule ceases to hold good, and the law becomes much more complicated in its expression. Since the mean diameter both of the Sun and Moon is about 32′, it follows that, when we see the lower edge of either of these luminaries apparently just *touching* the horizon, in *reality* its whole disc is completely *below* it, and would

[b] Since the barometer rises with an increase in the weight and density of the air, its rise causes an augmentation, and its fall a decrease, of refraction. It will be tolerably near the truth if we assume that the refraction at any given altitude is increased or diminished by $\frac{1}{300}$ of its mean amount for every 10th of an inch by which the barometer exceeds or falls short of 30 inches.

[c] Also as an increase of temperature causes a decrease of density, it follows that the elevation of the thermometer diminishes the effect of refraction, the barometer remaining stationary. We may assume that the refraction at any given altitude is increased or diminished by $\frac{1}{420}$ of its mean amount for each degree by which the thermometer exceeds or falls short of the mean temperature of 55° Fahr.

[d] See *post*, Book XI.

be altogether hidden by the convexity of the Earth were it not for the refraction.

It is under these circumstances that one of the most curious effects resulting from atmospheric refraction may often be noticed, namely the oval outline presented by the Sun and Moon when near the horizon. This arises from the unequal refraction of the upper and lower limbs. The lower limb being nearer the horizon, is more affected by refraction, and consequently is raised in a greater degree than the upper limb, "the effect being to bring the two limbs apparently closer together by the difference of the two refractions. The form of the disc is therefore affected as if it were pressed between two forces, one acting above and the other below, tending to compress its vertical diameter, and to give it the form of an ellipse, the lesser axis of which is vertical and the greater horizontal."

The dim and hazy appearance of objects in the horizon is not only occasioned by the rays of light having to traverse a larger space in the atmosphere, but also by their having to pass through the lower and denser part. "It is estimated that the solar light is diminished 1300 times in passing through these lower strata, and we are thereby enabled to gaze upon the Sun, when setting, without being dazzled by his beams." Or, as Bouguer put it, the Sun's brilliancy at 40° above the horizon is 1000 times greater than it is at 1°.

"The dilated size (generally) of the Sun or Moon when seen near the horizon beyond what they appear to have when high up in the sky, has nothing to do with refraction. It is an illusion of the judgment, arising from the terrestrial objects interposed, or placed in close comparison with them [e]. In that situation we view and judge of them as we do of terrestrial objects—in detail, and with an acquired habit of attention to parts. Aloft we have no associations to guide us, and their insulation in the expanse of the sky leads us rather to under-value than to over-rate their apparent magnitudes. Actual measurement with a proper instrument corrects our error, without however dispelling our illusion. By this

[e] This explanation of Sir J. Herschel's has been disputed, but its general correctness is rendered highly probable by the fact that the apparent size of a balloon varies in precisely the same way, according as it is high up in the air or near the horizon.

we learn that the Sun, when just on the horizon, subtends at our eyes almost exactly the same, and the Moon a materially *less* angle than when seen at a great altitude in the sky, owing to its greater distance from us in the former situation as compared with the latter[f]." Guillemin remarks that if the Moon, when in the horizon, be looked at through a tube, the illusion will disappear.

Claudius Ptolemy was the first who remarked that a ray of light proceeding from a star to the Earth undergoes a change of direction in passing through the atmosphere[g]. He moreover stated that the displacement is greatest at the horizon, diminishes as the altitude increases, and finally vanishes altogether at the zenith—an assertion which we have already seen to be perfectly correct. In the 16th century Tycho Brahe also investigated the subject of refraction; and his results, though by no means so accurate as those of Ptolemy, are interesting from the fact that they were the first which were reduced to the form of a Table. Since this period many astronomers have devoted their attention to the matter, and the Tables now in most general use are those of Bessel.

Twilight.—This is another phenomenon depending on the agency of the atmosphere with which the Earth is surrounded. It is due partly to refraction and partly to reflection, but chiefly to the latter cause. After sunset the Sun still continues to illuminate the clouds and upper strata of the air, just as it may be seen shining on the tops of hills long after it has disappeared from the view of the inhabitants of adjacent plains. The air and clouds thus illuminated reflect back part of the light to the surface beneath them, and thus produce, after sunset and before sunrise, in a degree more or less feeble according as the Sun is more or less depressed, that which we call "twilight." Immediately after the Sun has disappeared below the horizon all the clouds in the vicinity are so highly illuminated as to be able to reflect an amount of light but little inferior to the direct light of the Sun. As the Sun, however, sinks lower and lower, less and less of the visible atmosphere receives its light, and consequently less and less of it is reflected to the Earth's surface surrounding the position

[f] Sir J. Herschel, *Outlines of Ast.*, p. 35.

[g] *Almag.*, lib. vii. cap. 6.

where the observer is stationed, until at length, though by slow degrees, all reflection is at an end, and night ensues. The same thing occurs before sunrise; the darkness of night gradually giving place to the faint light of dawn, until the Sun appears above the horizon and produces the full light of day.

The duration of twilight is usually reckoned to last until the Sun's depression below the horizon amounts to 18°: this, however, varies: in the Tropics a depression of 16° or 17° is sufficient to put an end to the phenomenon, but in England a depression of 17° to 21° is required. The duration of twilight differs in different latitudes; it varies also in the same latitude at different seasons of the year, and depends in some measure on the meteorological condition of the atmosphere. Strictly speaking, in the latitude of Greenwich there is no true night from May 22 to July 21, but constant twilight from sunset to sunrise. Twilight reaches its minimum 3 weeks before the vernal equinox and 3 weeks after the autumnal equinox, when its duration is $1^h\ 50^m$. At midwinter it is longer by about 17^m, but the augmentation is frequently not perceptible, owing to the greater prevalence of clouds and haze at that season of the year, which intercept the light and hinder it from reaching the Earth. The duration is least at the equator ($1^h\ 12^m$), and increases as we approach the Poles, for at the former there are 2 twilights every 24 hours, but at the latter only 2 in a year, each lasting about 50 days. At the North Pole the Sun is below the horizon for 6 months; but from January 29 to the vernal equinox, and from the autumnal equinox to Nov. 12, the Sun is less than 18° below the horizon: so that there is twilight during the whole of these intervals, and thus the length of the actual night is reduced to 2½ months. The length of the day in these regions is about 6 months, during the whole of which time the Sun is constantly above the horizon. The general rule is, *that to the inhabitants of an oblique sphere the twilight is longer in proportion as the place is nearer the elevated pole*[h]. Under some circumstances a secondary twilight may be noticed[i].

[h] A valuable memoir on twilight, by J. F. J. Schmidt, will be found in *Ast. Nach.* vol. lxiii. No. 1495, Oct. 14, 1864. An abstract of it is given in the *Intell. Obs.*, vol. vii. p. 135, March 1865.

[i] Sir J. Herschel, *Outlines of Ast.*, p. 34.

BOOK IV.

COMETS.

CHAPTER I.

GENERAL REMARKS.

Comets always objects of popular interest—and alarm.—Usual phenomena attending the developement of a Comet.—Telescopic Comets.—Comets diminish in brilliancy at each return.—Period of Revolution.—Density.—Mass.—Lexell's Comet.—General influence of Planets on Comets.—Comets move in 1 of 3 kinds of orbits.—Elements of a Comet's orbit.—For a parabolic orbit, 5 in number.—Direction of motion.—Eccentricity of an elliptic orbit.—The various possible sections of a cone.—Early speculations as to the paths in which Comets move.—Comets visible in the daytime.—Breaking up of a Comet into parts.—Instance of Biela's Comet.—Liais's observations of Comet iii. 1860.—Comets probably self-luminous.—Existence of phases doubtful.—Comets with Planetary discs.—Phenomena connected with the tails of Comets.—Usually in the direction of the radius vector.—Vibration sometimes noticed in tails.—Olbers's hypothesis.—Transits of Comets across the Sun's disc.—Variation in the appearance of Comets exemplified in the case of that of 1769.—Transits of Comets across the Sun.

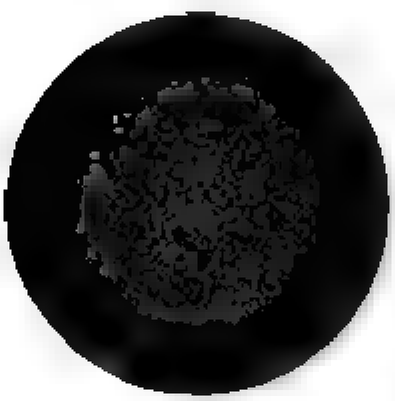
THE heavenly bodies which will now come under our notice are amongst the most interesting with which the astronomer has to deal. Appearing suddenly in the nocturnal sky, and often having attached to them tails of immense size and brilliancy, comets were well calculated in the earlier ages of the world to attract the attention of all, and to excite the fear of many. It is the unanimous testimony of history, during a period of upwards of 2000 years, that comets were always considered to be peculiarly "ominous of the wrath of Heaven, and as harbingers of wars and famines, of the dethronement of monarchs, and the dissolution

of empires." I shall hereafter examine this question at greater length. Suffice it for me here to quote the words of the Poet, who speaks of—

> "The blazing Star,
> Threat'ning the world with famine, plague, and war;
> To princes, death; to kingdoms, many curses;
> To all estates, inevitable losses;
> To herdsmen, rot; to ploughmen, hapless seasons;
> To sailors, storms; to cities, civil treasons."

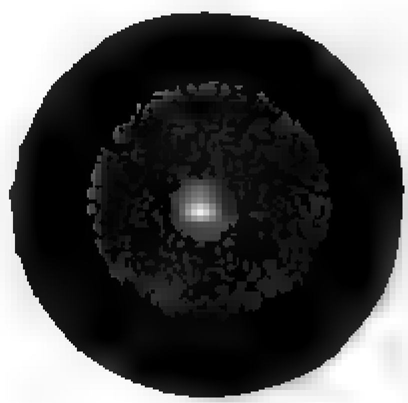
However little attention might have been paid by the ancients to the more ordinary phenomena of nature (which, however, were very well looked after), yet certain it is that comets and total eclipses of the Sun were not easily forgotten or lightly passed over; hence the aspects of remarkable comets that have appeared at various times have been handed down to us, often with circumstantial minuteness.

Fig. 97



TELESCOPIC COMET WITHOUT A NUCLEUS.

Fig. 98.



TELESCOPIC COMET WITH A NUCLEUS.

A comet usually consists of 3 parts, developed somewhat in the following manner:—A faintly luminous speck is discovered by the aid of a good telescope; the size increases gradually; and after some little time a *nucleus* appears—that is, a part which is more condensed in its light than the rest, and is sometimes circular, sometimes oval, and sometimes (but very rarely) presents a radiated appearance. Arago has remarked that this nucleus is generally eccentrically placed in the head, lying towards the margin nearest the Sun. Both the size and the brilliancy of the object progressively increase; the *coma*, or cloud-like mass around the nucleus, becomes less regular; and a tail begins to form, which becomes fainter as it recedes from the body of the comet. This tail increases

in length so as sometimes to spread across a large portion of the heavens; sometimes there are more tails than one, and occasionally the tail is much narrower in some parts than in others. The comet approaches the Sun in a curvilinear path, which frequently differs but little from a right line. It generally crosses that part of the heavens in which the Sun is situated so near the latter body as to be lost in its rays; but it emerges again on the other side, frequently with increased brilliancy and increased length of tail. The phenomena of disappearance are then not unlike those which marked the original appearance but in the reverse order.

In magnitude and brightness comets exhibit great diversity: some are so bright as to be visible in the daytime; others, indeed the majority, are quite invisible, except with powerful optical assistance. These latter are usually called *telescopic comets*. The appearance of the same comet at different periods of its return is so varying that we can never certainly identify a given comet with any other by any mere physical peculiarity of size or shape until its elements have been calculated and compared. It is now known that "the same comet may, at successive returns to our system, sometimes appear tailed, and sometimes without a tail, according to its position with respect to the Earth and the Sun; and there is reason to believe that comets in general, from some unknown cause, decrease in splendour in each successive revolution[a]."

The periods of comets in their revolutions vary greatly, as also do the distances to which they recede from the Sun. Whilst the orbit of Encke's comet is contained within that of Jupiter, the orbit of Halley's extends far beyond that of Neptune. Some comets indeed proceed to a much greater distance than this, whilst others are supposed to move in curves which do not, like the ellipse, return into themselves. In this case they never come back to the Sun. These orbits are either parabolic or hyperbolic. The density, and also the *mass*, of comets is exceedingly small, and their tails consist of matter of such extreme tenuity that even small stars are visible through them—a fact first recorded by Seneca. That the matter of comets is exceedingly rare is sufficiently proved by the fact that they have at times passed very near to some of the planets without disturbing in any appreciable degree the motions of the

[a] Smyth, *Cycle*, vol. i. p. 235.

said planets. Thus the comet of 1770 (Lexell's) in its advance towards the Sun, became entangled amongst the satellites of Jupiter, and remained near them for 4 months, without in the least affecting them as far as we know. It can therefore be shewn that this comet's mass could not have been so much as $\frac{1}{5000}$ that of the Earth. The same comet also came very near to the Earth on July 1—its distance from it at 5^h on that day being about 1,400,000 miles—so that had its quantity of matter been equal to that of the Earth, it would, by its attraction, have caused our globe to move in an orbit so much larger than it does at present that it would have increased the length of the year by $2^h\ 47^m$, yet no sensible alteration took place. The comet of 837 remained for a period of 4 days within 3,700,000 miles of the Earth without any untoward consequences. Very little argument, therefore, suffices to shew the absurdity of the idea of any danger happening to our planet from the advent of any of these wandering strangers. Indeed, instead of comets exercising any influence on the motions of planets, there is the most conclusive evidence that the converse is the case—that planets influence comets. This fact is strikingly exemplified in the history of the comet of 1770, just mentioned. At its appearance it was found to have an elliptical orbit, requiring for a complete revolution only 5½ years; yet although this comet was a large and bright one, it had never been observed before, and has moreover never been seen since; the reason being that the influence of the planet Jupiter, in a short period, completely changed the character of its path. "Du Séjour has proved that a comet, whose mass is equal to that of the Earth, which would pass at a distance of 37,500 miles only, would extend the length of the year to $367^d\ 16^h\ 5^m$, and could alter the obliquity of the ecliptic to the extent of 2°. Notwithstanding its enormous mass and the smallness of its distance, such a body would then produce upon our globe only one kind of revolution,—that of the calendar [b]."

A comet may move in either an elliptic, parabolic, or hyperbolic orbit; but for reasons with which mathematical readers are acquainted, no comet can be periodical which does not follow an elliptic path. In consequence, however, of the comparative facility with which the parabola can be calculated, astronomers are in the

[b] Arago, *Pop. Ast.*, vol. i. p. 642, Eng. ed.

habit of applying that curve to represent first of all the orbit of any newly-discovered body. Parabolic *elements* having been obtained, a search is then made through a catalogue of comets, to see whether the new elements bear any resemblance to those of any object that has been previously observed; if so, calculations for an elliptic orbit are undertaken; whence a period may be deduced.

The elements of a parabolic orbit are 5 in number:—

1. *The time of perihelion passage*, or the moment when the comet arrives at its least distance from the Sun [c]—denoted by PP, or τ.

2. *The longitude of the perihelion*, or the longitude of the comet when it reaches that point.—π.

3. *The longitude of the ascending node* of the comet's orbit, as seen from the Sun.—☊.

4. *The perihelion distance*, or the distance of the comet from the Sun expressed in radii of the Earth's orbit.—q.

5. *The inclination of the orbit*, or the angle between the plane of the orbit and the ecliptic.—ι.

It is also necessary to know whether the comet moves in the order of the signs of the zodiac, or in the contrary direction: in the former case its movement (μ) is said to be *direct* (+), in the latter, *retrograde* (−). In an elliptic orbit we require to know the eccentricity (ϵ): this is sometimes expressed by the angle ϕ, of which the previous quantity (ϵ) is the sine. From this, with the perihelion distance, we can ascertain the length of the major axis, and consequently the comet's periodic time. Be it remembered that the eccentricity is not the linear distance of the centre of the ellipse from the focus, but the ratio of that quantity to the semi-axis major.

Up to the present time the orbits of more than 300 comets have been calculated [d]: a Table of these will be given hereafter.

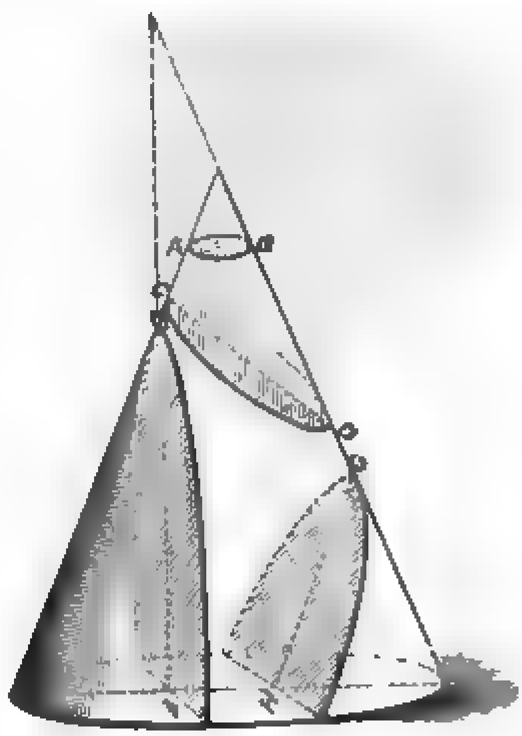
Fig. 99 represents the various possible sections of a right cone, and will convey a better idea of the orbits of comets than could be given by description. When a right cone is cut at right angles to its axis, the resulting section A B will be a circle; no comet, how-

[c] In an elliptic orbit the corresponding point of extreme distance from the Sun is called the *Aphelion*.

[d] Gauss's *Theoria Motus Corporum Cœlestium*, 4to. Hamburg, 1809. is reckoned the standard work on the subject of orbits. See also a paper by Airy, in *Memoirs* R.A.S., vol. xi. p. 181. 1840.

ever, revolves in a circular or even nearly circular orbit. When a cone is cut obliquely, so that the inclination of the cutting plane to the axis of the cone is *greater than* the constant angle formed by the generating line of the cone and the axis, as C D, the resulting section will be an *ellipse*, the shape of which will vary from almost a circle on the one hand to almost a parabola on the other according to the amount of the obliquity. When a cone is cut in a direction, so that the inclination of the cutting plane to the axis of the cone is *less than* the constant angle formed by the generating line of the cone and the axis, as E F, the resulting section will be a *hyperbola*. When a cone is cut in a direction so that the inclination of the cutting plane to the axis of the cone is *equal to* the constant angle formed by the generating line of the cone and the axis, as G H, the resulting section will be a *parabola*.

Fig. 99.



The various Sections of a Cone.

To the early astronomers the motions of comets gave rise to great embarrassment. Tycho Brahe thought that they moved in circular orbits; Kepler, on the other hand, suggested right lines. Hevelius seems to have been the first to remark that cometary orbits were much curved near the perihelion, the concavity being towards the Sun. He also threw out an idea relative to the parabola, as being the form of a comet's path, though it does not seem to have occurred to him that the Sun was likely to be the focus. Borelli suggested an ellipse or a parabola. Sir William Löwer was probably the first to hint that comets sometimes moved in very eccentric ellipses; this he did in his letter to his "especiall goode friend, Mr. Thomas Harryot," dated Feb. 6, 1610. Dörfel, a native of Upper Saxony, was the first practical man: he shewed that the comet of 1680 moved in a parabolic orbit.

History informs us that some comets have shone with such splendour as to have been distinctly seen in the daytime. The comets of B.C. 43, A.D. 575 (?), 1106, 1402 (i), 1402 (ii), 1472,

1532, 1577, 1618 (ii), 1744, 1843 (i), 1847 (i), and 1853 (iii), are the principal ones which have been thus observed. There are some well-established instances of the separation of a comet into 2 or more distinct portions. Seneca mentions, on the authority of Ephorus, a Greek author, that the comet of 371 B.C. separated into 2 parts which pursued different paths[e]. Seneca seems to distrust the statement he repeats, but Kepler accepted it after what he had himself seen in regard to the great comet of 1618. In the case of this comet Cysatus noticed an evident tendency to break up. When first seen this comet was a nebulous object, but some weeks afterwards it appeared to consist of a group of several small nebulosities. But the most recent and best authenticated instance of this character is that of Biela's comet in 1845–6. When first detected, on Nov. 28, it presented the appearance of a faint nebulosity, almost circular, with a slight condensation towards the centre: on Dec. 19 it appeared somewhat elongated, and by the end of the month the comet had actually separated into two distinct nebulosities which travelled together for more than 3 months: the maximum distance between the parts (157,240 miles) was attained on March 3, 1846, after which it began to diminish until the comet was lost sight of in April. At its return in 1852 the separation was still maintained, but the interval had increased to 1,250,000 miles. As we shall have to speak of Biela's comet again in a later chapter no more need be said about it here.

Fig 100.

The 1st Comet of 1847, visible at noon on March 30. (*Hind.*)

Biela's comet as regards its duplicity does not stand alone amongst modern comets. A comet seen in February and March 1860, only by M. Liais in Brazil, consisted of a principal nebulosity accompanied at a short distance by a second nebulosity. It is to be regretted that this object remained visible for so short a time as a fortnight, and that our knowledge of it depends on the authority of but one observer, and he a Frenchman[f].

[e] *Quæst. Nat.*, lib. vii. cap. 16. He says:—"Ephoro viro non religiosissime fidei, sæpe decipitur, sæpe decipit."

[f] *Ast. Nach.*, vol. lii. No. 1248. April 14. 1860.

The question whether or not comets are self-luminous has in one sense never been satisfactorily settled, yet it cannot be doubted that they are self-luminous. The high magnifying power that may sometimes be brought to bear on them tends to shew that they shine by their own light. Sir W. Herschel was of this opinion from his observations of the comets of 1807 and 1811 (i)[g]. It is manifest, however, that if the existence of phases could be certainly known, this would furnish an irrefragable proof that the

Fig. 101.

BIELA'S COMET, Feb. 19, 1846. (*O. Struve.*)

comet exhibiting such shone by reflected light. It has been asserted from time to time that such phases have been seen, but none of the statements ever made seem to deserve attention. Delambre mentions that the registers of the Royal Observatory at Paris exhibit undoubted evidence of the existence of phases in the comet of 1682: but neither Halley nor any other astronomer who observed this comet has given the slightest intimation that any phase-phenomena were visible. James Cassini mentions the existence of phases in the comet of 1744[h]; on the other hand, Heinsius and Chésaux, who paid particular attention to this comet, positively deny having seen anything of the kind. More recently Cacciatore, of Palermo, expressed a decided conviction that he had seen a crescent in the comet of 1819. Arago sums up by saying that the observations of M. Cacciatore prove only that the nuclei of

g *Phil. Trans.*, vol. cii. p. 115. 1812.
h *Mém. Acad. des Sciences*, 1744, p. 303.

comets are sometimes very irregular[i]. Sir W. Herschel states that he could see no signs of any phases in the comet of 1807, although he fully ascertained that a portion of its disc was not illuminated by the Sun at the time of observation[k]. The general opinion is against the existence of phases, and thus we must consider that comets shine by their own inherent light; nevertheless the observations of Airy and others on Donati's comet in 1858 point to exactly the opposite conclusion, at least as regards the *tail* of that comet[l].

Some comets have been observed with round and well-defined planetary discs. Seneca relates that one appeared after the death of Demetrius, king of Syria, but little inferior to the Sun [in size?]; being a circle of red fire, sparkling with a light so bright as to surmount the obscurity of night. The comet of 1652, seen by Hevelius, was almost as large as the Moon, though not nearly so bright. The comets of 1665 and 1682 are described as having been as well defined in their outlines as the planet Jupiter.

There are several curious phenomena connected with the tails of comets which require notice. It was observed by Pierre Apian that the trains of 5 comets, seen by him between the years 1531 and 1539, were turned *from the Sun*, forming more or less a prolongation of the radius vector, the imaginary line joining the Sun and the comet; as a general rule, this has been found to be the case[m], although exceptions do occur.

Thus the tail of the comet of 1577 deviated 21° from the line of the radius vector. Valz has stated that the tails of comets iv. and v. of 1863 deviated from the *planes of the orbits*, and that only 2 other comets are known the tails of which did the same[n]. In some few instances, where a comet has had more than one tail, the 2nd has extended more or less *towards* the Sun; this was the case with the comets of 1823 and 1851 (iv). Although comets usually have but one tail, yet 2 is by no means an uncommon number; and indeed the great comet of 1825 had 5 tails (Dunlop), and that of 1744 as many as 6, according to Chésaux. The tails of many comets are curved, so as to resemble in appearance a sabre;

[i] *Pop. Ast.*, vol. i. p. 627, Eng. ed.

[k] *Phil. Trans.*, vol. xcviii. p. 156. 1808.

[l] *Green. Obs.*, 1858, p. 90.

[m] The researches of M. E. Biot shew that this fact was noticed by the Chinese long before the time of Apian, to wit, in 837. *Comptes Rendus*, vol. xvi. p. 751. 1843.

[n] *Comptes Rendus*, vol. lviii. p. 853. 1864.

such was the case with the comets of 1844 (iii), and 1858 (vi), amongst others. The comet of 1769 had a double curved tail, thus ∽, according to La Nux, who observed it at the Isle of Bourbon.

The trains of some great comets have been seen to vibrate in a manner somewhat similar to the Aurora Borealis. The tails of the comets of 1618 (ii) and 1769 may be cited as instances: the observer in the latter case was no less a person than Pingré. The vibrations commence at the head, and appear to traverse the whole length of the comet in a few seconds. It was long supposed that the cause was connected with the nature of the comet itself, but Olbers has pointed out that such appearances could only be fairly attributed to the effects of our own atmosphere, for this reason:—"The various portions of the tail of a large comet must often be situated at widely different distances from the Earth; so that it will frequently happen that the light would require several minutes longer to reach us from the extremity of the tail than from the end near the nucleus. Hence, if the coruscations were caused by some electrical emanation from the head of the comet, even if it occupied but 1 second in passing over the whole surface, several minutes must necessarily elapse before *we* could see it reach the tail. This is contrary to observation [o], the pulsations being almost instantaneous." Instances of this phenomenon are not very common. The most recent case is that of Coggia's comet of 1874. An English observer at Hereford named With noticed an "oscillatory motion of the fan-shaped jet upon the nucleus as a centre which occurred at intervals of from 3 to 8 secs. The fan seemed to 'tilt over' from the preceding to the following side, and then appeared sharply defined and fibrous in structure, then it became nebulous, and all appearance of structure vanished [p]."

Respecting the physical constitution of the tails of comets it may be said that probably in many cases they are hollow cones. This theory would accord with the observed fact that single tails usually increase in width towards their extremities and are divided in the middle by a dark band, the brilliancy of the margins exceeding that of the more central portions. Similarly, comets with

[o] *Mém. Acad. des Sciences*, 1775, p. 392.
[p] *Ast. Reg.*, vol. xiv. p. 13. Jan. 1876.

tails of tolerably uniform width throughout may be regarded as hollow cylinders[q].

The following is an excellent instance of the ever-changing appearance of comets; it relates to that of 1769. On Aug. 8, Messier, whilst exploring with a 2-foot telescope, perceived a round nebulous body, which turned out to be a comet. On the 15th the tail became visible to the naked eye, and appeared to be about 6° in length; on the 28th it measured 15°; on Sept. 2, 36°; on the 6th, 49°; and on the 10th, 60°. The comet having now plunged into the Sun's rays, ceased to be visible. On Oct. 8, the perihelion passage took place; on the 24th of the same month it reappeared, but with a tail only 2° long; on Nov. 1 the tail measured 6°; on the 8th it was only $2\frac{1}{2}$°; on the 30th it was $1\frac{1}{2}$°: the comet then disappeared.

Transits of comets across the Sun no doubt occasionally happen, but only one such spectacle has ever been witnessed, and even then the nature of the sight was not understood till afterwards. The German Sun-spot observer, Pastorff, noticed on June 26, 1819, a round dark nebulous spot on the Sun; it had a bright point in its centre. Subsequently when the orbit of comet (ii) 1819 came to be investigated, Olbers pointed out that the comet must have been projected on the Sun's disc between 5^h and 9^h a.m. Bremer M.T. Pastorff asserted that his "round nebulous spot" was the comet. Olbers, and with him Schumacher, disputed the claim, but there is now no doubt whatever about it[r]. Comet v. of 1826 was calculated to cross the Sun on Nov. 18, 1826, but owing to the general prevalence of bad weather in Europe, only 2 observers were fortunate enough to be able to see the Sun on that day, and neither of them could obtain a glimpse of the comet.

[q] This work is a record of facts rather than of theories, and is too bulky already. Otherwise I might have given it a great expansion by embarking on a review of some of the chief theories which have been broached respecting Comets.

[r] For some further particulars as to this controversy see Webb's *Celest. Obj.*, p. 38, where there is also a fac-simile of Pastorff's original sketch.

CHAPTER II.

PERIODIC COMETS.

Periodic Comets conveniently divided into three classes.—Comets in Class I.—Encke's Comet.—The resisting medium.—Table of periods of revolution.—Di Vico's Comet.—Pons's Comet of 1819.—Brorsen's Comet.—Biela's Comet.—D'Arrest's Comet.—Faye's Comet.—Méchain's Comet of 1790.—List of Comets presumed to be of short periods but only once observed.—Comets in Class II.—Westphal's Comet.—Pons's Comet of 1812.—Di Vico's Comet of 1846.—Olbers's Comet of 1815.—Brorsen's Comet of 1847.—Halley's Comet.—Of special interest.—Résumé of the early history of Haelly's labours.—Its return in 1759.—Its return in 1835.—Its history prior to 1531 traced by Hind.—Comets in Class III not requiring detailed notice.

THE comets which I propose to treat of in the present chapter may be conveniently divided into 3 classes:—

1. Comets of short periods.
2. Comets revolving in about 70 years.
3. Comets of long periods.

The following are the comets belonging to Class I, with which we are best acquainted:—

Name.	Period.	Next Return.
	Years.	
1. Encke	3·296	1878 July
2. Di Vico	5·469	1877 (?)
3. Winnecke	5·54	1880 Sept.
4. Brorsen	5·581	1879 May
5. Biela	6·617	1879 March
6. D'Arrest	6·64	1877 May
7. Faye	7·44	1881 June
8. Tuttle	13·66	1885 July

Encke's Comet.

No. 1 is by far the most interesting comet in the list, and I shall therefore review its history somewhat in detail.

On Jan. 17, 1786, Méchain, at Paris, discovered a small telescopic comet near the star β in the constellation Aquarius. On the following day he announced his discovery to Messier, who, from some cause or other, did not see it till the 19th, on which night it was also observed by F. Cassini and the original discoverer. It was tolerably large and well defined, and had a bright nucleus, but no tail.

On Nov. 7, 1795, Miss Caroline Herschel, sister of Sir W. Herschel, discovered a small comet, about 5′ in diameter, without a nucleus, but yet having a slight central condensation of light. Olbers observed it on Nov. 21, when it was too faint to allow of the field being illuminated, and he was obliged to compare it with stars in the same parallel by noting the times of transit across the field of view. It was round, badly defined, and about 3′ in diameter. The orbit greatly perplexed the calculator, and Prosperin declared that no parabola would satisfy the observations.

On Oct. 19, 1805, Thulis, at Marseilles, discovered a small comet, which was faintly visible to the naked eye. Huth stated that on the 20th it was very bright in the centre, though without a nucleus, and 4′ or 5′ in diameter. On Nov. 1 the same observer saw a tail 3° long. Several parabolic orbits were calculated, and one elliptic one by Encke, to which a period of 12·127 years was assigned.

On Nov. 26, 1818, the indefatigable Pons, of Marseilles, discovered a telescopic comet in Pegasus, which was very small and ill-defined. As it remained visible for nearly 7 weeks, or till Jan. 12, 1819, a rather long series of observations was obtained; and Encke, finding that under no circumstances whatever would a parabolic orbit fairly represent them, determined rigorously to investigate the elements according to the method of Gauss, then but little practised. Having done this, he found that the true form of the orbit was elliptical, and that it had a period of about 3½ years. On looking over a catalogue of all the comets then known, he was struck with the similarity which the elements obtained by him bore to those of the comets of 1786 (i), 1795, and

1805, and he was strongly impressed with the idea that the comet whose movements were then under investigation was identical with those comets, more particularly as, on the assumption of a 3⅓-year period, it might be expected to have been in perihelion at about those epochs. This question could only be settled by calculating backwards the effects of planetary perturbation, which Encke by an extraordinary effort did in 6 weeks. He was accordingly able to assure himself of the identity of the comet of 1818 with the 3 above-mentioned ones, and also that between 1786 and 1818 it had passed through perihelion 7 times without being seen.

Encke then proceeded to calculate its next return, and he announced that the comet would arrive at perihelion on May 24, 1822, after being retarded about 9 days by the influence of the planet Jupiter.

"So completely were these calculations fulfilled, that astronomers universally attached the name of 'Encke' to the comet of 1819, not only as an acknowledgment of his diligence and success in the performance of some of the most intricate and laborious computations that occur in practical astronomy, but also to mark the epoch of the first detection of a comet of short period—one of no ordinary importance in this department of science."

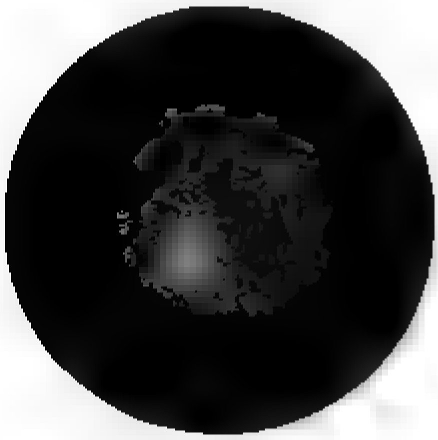
It unfortunately happened that at its return in 1822 the position of the comet in the heavens was such as to render it invisible in the Northern hemisphere. It was therefore systematically watched by only one observer, M. Rümker, who discovered it on June 2, at the private observatory of Sir T. M. Brisbane, at Paramatta, New South Wales, and he was able to follow it for only 3 weeks. Rümker's observations were, however, so far valuable, that besides shewing that the comet actually did come back, they furnished Encke with the means of predicting with greater certainty its next return, which he found would occur on Sept. 16, 1825.

On this occasion it was first seen by Valz, on July 13, but was discovered independently by more than one other astronomer. Cacciatore, of Palermo, described it as being round, with a faint nebulosity, and about 1° 30′ in diameter.

The next return to perihelion took place on Jan. 9, 1829. Struve, at Dorpat, found it on Oct. 13, 1828; Harding, at Göttingen, and

Gambart, at Marseilles, both saw it for the first time on the same day, Oct. 27, the former having been on the look-out since Aug. 19, and it was very generally observed till the end of December in the same year. On Nov. 30 it was visible to the naked eye as a star of the 6th magnitude, and a week afterwards it had become as bright as a star of the 5th magnitude. The outline of the coma was slightly oval, with the minor axis (on one occasion at least) pointing towards the Sun.

Fig. 102



Encke's Comet: Nov. 30, 1828. (*W. Struve.*)

The 4th of May, 1832, was calculated as the epoch of the next perihelion passage. The comet was discovered by Mossotti, at Buenos Ayres, on June 1, and by Henderson, at the Cape of Good Hope, on the following night. Harding, at Göttingen, who saw it on Aug. 21, was the only European observer who caught a glimpse of it, owing to its path lying chiefly in the Southern heavens.

The next return to perihelion was fixed for Aug. 26, 1835. The comet was seen both in Europe and at the Cape of Good Hope.

Dec. 9, 1838, was the epoch of the next perihelion passage; and as the comet's apparent path would be such as to allow observations to be made in Europe under very favourable conditions, it was looked for with much interest. Boguslawski discovered it on Aug. 14; but Galle, at Berlin, did not see it till Sept. 16; and it was not generally seen till the middle of October. At about the end of the first week in November it was visible to the naked eye in Draco; with a telescope a rather bright nucleus was seen, and the general form of the coma was that of a broad parabola.

The account of this return would be incomplete were I not to refer to a peculiarity connected with the comet's motion, which, though it attracted Encke's attention as far back as 1818, may be said not to have been brought into special prominence till the return of 1838. He found that, notwithstanding every allowance being made for planetary influences, the comet always attained its perihelion distance about 2½ hours sooner than his calculations

led him to expect. In order to account for this gradual diminution of the period of revolution, which in 1789 was nearly 1213 days, but in 1838 was scarcely $1211\frac{1}{10}$ days, Encke conjectured the existence of a thin ethereal medium, sufficiently dense to produce an effect on a body of such extreme tenuity as the comet in question, but incapable of exercising any sensible influence on the movements of the planets. "This contraction of the orbit must be continually progressing, if we suppose the existence of such a medium; and we are naturally led to inquire, What will be the final consequence of this resistance? Though the catastrophe may be averted for many ages by the powerful attraction of the larger planets, especially Jupiter, will not the comet be at last precipitated on the Sun? The question is full of interest, though altogether open to conjecture."

The following table, published by Encke[a], will more clearly illustrate the changes in the comet's periodic time:—

Year of PP.	Period, Days.	Year of PP.	Period, Days.
1786		1825	1211·55
(1789)	1212·79	1829	1211·44
(1792)	1212·67	1832	1211·32
1795	1212·55	1835	1211·22
(1799)	1212·44	1838	1211·11
(1802)	1212·33	1842	1210·98
1805	1212·22	1845	1210·88
(1809)	1212·10	1848	1210·77
(1812)	1212·00	1852	1210·65
(1815)	1211·89	1855	1210·55
1819	1211·78	1858	1210·44
1822	1211·66		

The propriety of this explanation of a resisting medium, has been warmly canvassed at different times, and it cannot be said to command universal assent. One strong point against it is, that not one of the other short-period comets (all of them of small size and, presumably, unimportant mass) yield any indications that they experience a like influence[b].

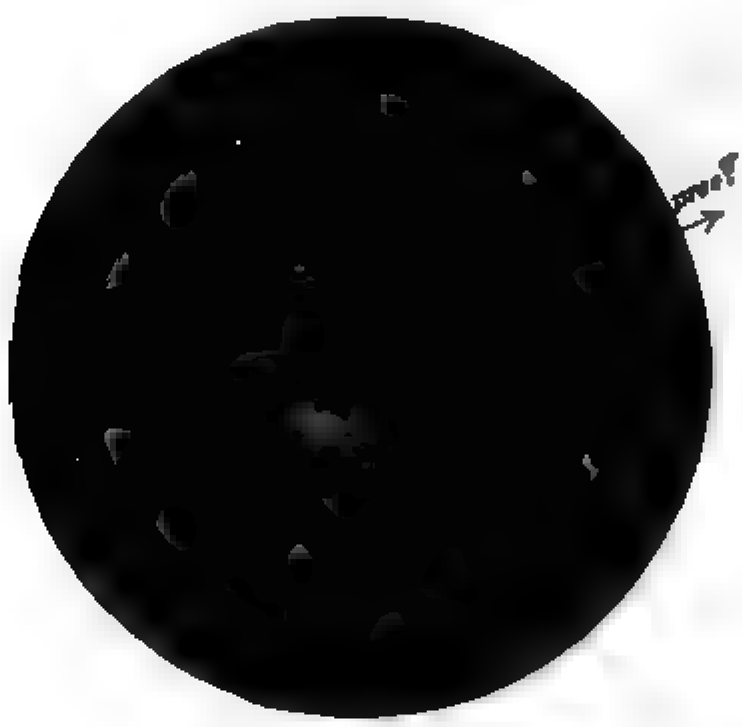
The 1838 return is also noticeable for an important discovery in physical astronomy which it, indirectly, was the cause of evolving.

[a] *Month. Not.*, vol. xix. p. 70. Dec. 1858.
[b] See a notice of a paper by A. Hall in *Month. Not.*, vol. xxxiii. p. 239. Feb. 1873.

In Aug. 1835 the comet passed very near the planet Mercury—so near, in fact, that Encke shewed that if Laplace's value of Mercury's mass were correct, the planet's attractive power would diminish the comet's geocentric R.A. on Nov. 2, 1838, by 58′, and increase its declination by 17′. As the observations indicated no such disturbance of the comet's orbit, it was obvious that the received mass of the planet was far too great, and a much lower value has since been adopted [o].

Passing over the returns of 1842 and 1845, as offering no features of particular interest, we find that in 1848, on Sept. 24, the diameter of the comet's head was 8′, and that it was just visible to

Fig. 103.



Encke's Comet: Nov. 5, 1871. (*Rev. H. C. Key.*)

the naked eye on Oct. 6, and for some weeks subsequently. Early in November it had a tail about 1° long, turned *from* the Sun, and another and smaller one directed *towards* that luminary. On Nov. 22, at midnight, the comet was distant but 3,600,000 miles from Mercury.

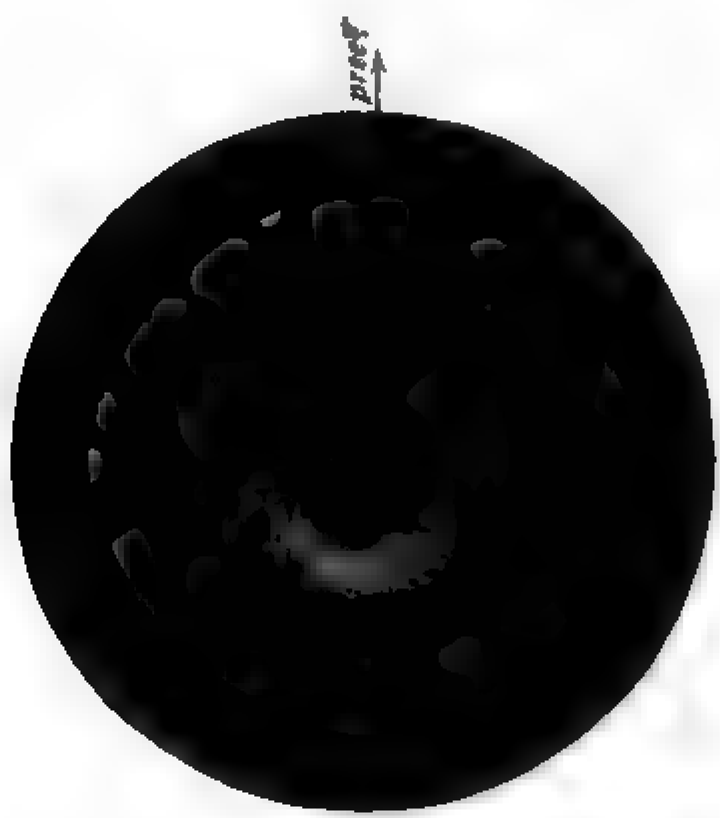
Passing over also the returns of 1852, 1855, and 1858, we arrive at that of 1862, the 17th on record. The passage through the perihelion took place on Feb. 6, but the comet was discovered

[o] In Hind's *Comets*, p. 65 *et seq.*, the general principles upon which these inquiries are conducted are laid down with that clearness of language for which that astronomer is noted in the treatment of difficult matters.

by Förster, at Berlin, as early as Sept. 28, 1861. It was then very faint, and difficult of observation. The same character applies to the return of 1865, which was observed only in the Southern hemisphere. In 1868 the comet was unfavourably placed and was seen by only a few observers.

In 1871 on the other hand, the comet was well seen and numerous observations of it were made. For a day or two in November, it was within the reach of telescopes of small dimensions. Some physical peculiarities were noted at this apparition

Fig. 104.



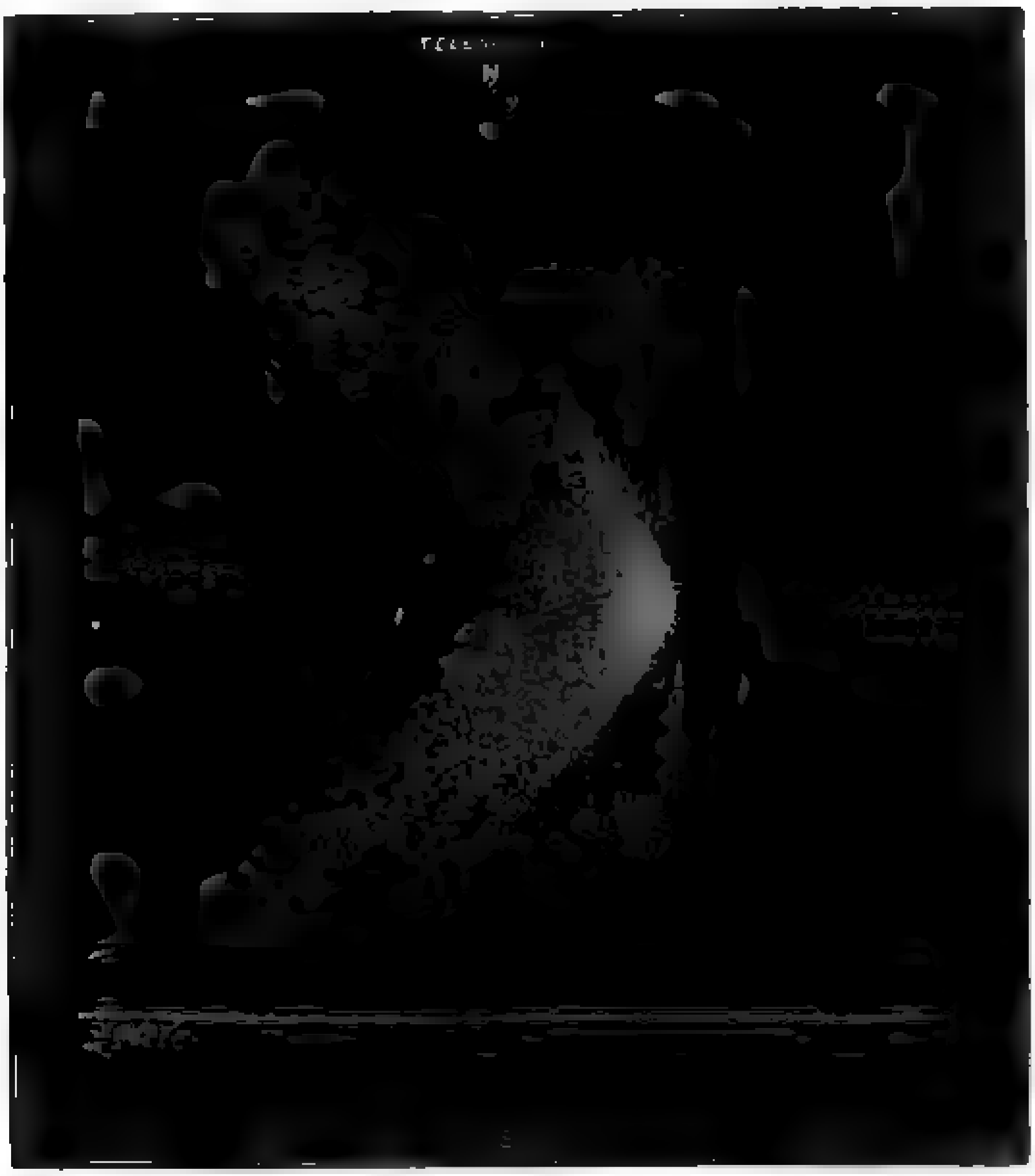
ENCKE'S COMET: Nov. 8, 1871. (*Rev. H. C. Key.*)

which deserve mention. When first discovered in August, the comet was a nearly round and faint nebulosity, without apparent condensation in any part. By the beginning of November, it had acquired a remarkable fan-like form, but the precise character of the exterior outline differed a good deal according to the power of the telescope employed. This will be readily understood by a comparison of the annexed engravings, Mr. Key's drawings on November 8 (and indeed his other 2 also) having been made with an 18-inch silvered glass reflector, whilst Mr. Carpenter used the great 12-inch equatorial at Greenwich.

Mr. Carpenter says[d] :—

"I was able to make out a considerable extension of the illumination beyond the bright fan-shaped condensation, but on one side (the spreading side) only. On the opposite side this diffused illumination appeared to be cut off nearly in a straight line immediately behind (following) the apex of the fan."

Fig. 105.



Encke's Comet: Nov. 9, 1871. (*J. Carpenter.*)

The Rev. H. C. Key speaking in the first instance of what he saw on December 3, says[e] :—

"The train following the comet was quite broad in my telescope, and could not be termed a 'ray.' You will observe two rays on the preceding side; these I have drawn as you see, but I am not perfectly certain that the effect was not in my own

[d] *Month. Not.*, vol. xxxii. p. 26. Nov. 1871.

[e] *Month. Not.*, vol. xxxii. p. 217. March 1872.

eye and not a reality. I took every precaution to find out; and at the time (as well as now) felt pretty well convinced that it was no illusion. Four or five times I left the telescope, and upon returning there were the rays in exactly the same spot and direction. I feel pretty confident of their reality (they were extremely faint), but, as I say, am not quite certain, as I sometimes see dark lines in the field when first going to the telescope. The comet never seemed to me to lose its elliptical form from the first night I saw it, Oct. 20th. I detected a nucleus for the first time on Nov. 7th. The train I mentioned before was much fainter than the main body of the comet, and I was able to trace it to a distance of about 32′ from the nucleus. I saw nothing like the drawing of the comet made at Greenwich."

Fig. 106.

ENCKE'S COMET: Dec. 3, 1871. (*Rev. H. C. Key.*)

Encke's comet returned to perihelion again in April 1875, but no observations were made calling for notice.

DI VICO'S COMET.

No. 2.—On Aug. 22, 1844, M. Di Vico, at Rome, discovered a telescopic comet, which, towards the end of the following month, became perceptible to the naked eye. With a telescope a bright stellar nucleus and a short tail were seen. It soon became evident that the observations could not be reconciled with any parabolic orbit, and elliptic elements were calculated by several computers. The most complete investigation is due to Brünnow, who found that the comet's periodic time was 1993 days. Carrying on his researches to the next return to perihelion, which was calculated

to occur in the spring of 1850, he found that "when the comet was near enough to the Earth to be otherwise discerned, it was always lost in the Sun's rays, the geocentric positions of the Sun and comet at perihelion being nearly the same, and continuing so for some months, on account of the apparent direct movement of both bodies."

Its next return to perihelion was fixed for Aug. 6, 1855; and as it would be favourably situated for observation hopes were entertained that it would again be detected. Such, however, was not the case; nor was it seen in 1861, 1866, or 1872, and therefore we are scarcely justified in including it in the list of "known" short-period comets. Certain computations by Le Verrier render it probable that this comet is identical with that of 1678.

Winnecke's Comet,

No. 3, was discovered by M. Pons, on June 12, 1819. Encke assigned to it a period of 5½ years, which, as the table will shew, was a very close approximation to the truth. It was not, however, seen from that time till March 8, 1858, when it was detected by Winnecke, at Bonn, and by him regarded as a new comet; but he soon ascertained the identity of the two objects. It must have returned in 1863, but was not on that occasion favourably placed for observation. The next return to perihelion occurred in June 1869. The comet was viewed by Winnecke himself on April 9, of that year, and is described by him as being faint, but not less than 6′ or 8′ in diameter. Winnecke's comet was again visible in 1875 passing through perihelion on March 11. Some calculations by Oppolzer have led him to think that this comet was observed previous to the occasion which has usually been considered its first discovery (namely its detection by Pons in 1819), and that it is identical with the comet discovered by Pons in Feb. 1808 (see the Catalogue of "Uncalculated" Comets, *post*, p. 372).

Brorsen's Comet,

No. 4, was detected by M. Brorsen, at Kiel, on Feb. 26, 1846. The observations shewed an elliptic orbit, and the epoch of the ensuing arrival at perihelion was fixed for Sept. 26, 1851, but its position then was not very favourable, owing to its proximity

to the Sun, and it escaped observation. Bruhns again discovered it on March 18, 1857. I saw it on March 23; it possessed the usual nebulous appearance common to these objects, and had a diameter of about 2′, though it was unfavourably placed in the morning twilight, which probably marred its brilliancy. This comet again returned to perihelion in April 1868 and Oct. 1873.

BIELA'S COMET,

No. 5, is another very remarkable periodic comet, even more interesting than Encke's, but for altogether a different reason; I shall therefore give its history at some length.

On March 8, 1772, Montaigne, at Limoges, discovered a comet in Eridanus, which, from want of suitable instruments, he was unable properly to observe, or to see at all after the 20th; Messier, however, saw it four times between March 26 and April 3.

On Nov. 10, 1805, Pons discovered a comet, which was found also by Bouvard on the 16th. It had a nucleus, and the diameter of the coma on Nov. 23 was 6′ or 7′. On Dec. 8 it was at its nearest point to the Earth, and Olbers saw it without a telescope. Bessel and others calculated elliptic elements, and its identity with the comet of 1772 was suspected, though no predictions as to its next return were ventured on.

On Feb. 27, 1826, M. Biela, at Josephstadt, Bohemia, discovered a faint comet in Aries, which Gambart found on March 9. The observations extended altogether over a period of 8 weeks, and it was soon made evident that the orbit was an ellipse of moderate eccentricity; and farther, that the comet was the same as that which had already been observed in 1772 and 1805.

In anticipation of its next return in 1832 investigations into the orbit of the comet and the perturbations by which it would be affected were undertaken by Santini, Damoiseau, and Olbers. Santini found that its period in 1826 was 2455 days, but that the attraction of the Earth, Jupiter, and Saturn would accelerate its next return by rather more than 10 days, which he accordingly fixed for Nov. 27, 1832. Damoiseau's investigations gave a similar result. Early in 1828 Olbers called attention to the fact that in 1832 the comet would pass within 20,000 miles of the Earth's *orbit;* but that as the Earth would not reach that particular point

till one month after the comet had passed it, no danger was to be apprehended. Astronomers were quite satisfied as regards this matter, but their confidence was not shared by the unscientific many, who were greatly alarmed lest a collision should take place, and our globe become a sufferer thereby.

Punctually at the time appointed the comet returned to perihelion, through which it passed within 12 *hours* of the time fixed by Santini five years previously. It was first seen at Rome on Aug. 23, but, owing to its excessive faintness, it was not generally observed till two months later.

The next return was calculated to take place on July 23, 1839, but in consequence of its close proximity to the Sun, the comet was not detected.

Continuing his researches, Santini fixed on Feb. 11, 1846, as the epoch of the next perihelion passage; and as it would be visible for a considerable period, much interest was excited amongst astronomers, who anticipated that a remarkably good opportunity would be afforded for correcting the theory of its motion.

Di Vico, at Rome, with the powerful telescope at his command, discovered it on Nov. 28, 1845, and Galle, at Berlin, saw it two days later; but by the generality of observers it was not seen till the second or third week in December. I have already adverted to the very curious phenomenon which took place at this apparition of Biela's comet. (See p. 284 *ante.*)

The comet returned again to perihelion in Sept. 1852, and was visible for three weeks. The same reason which prevented it from being seen in 1839 also caused it to pass undetected in May 1859; so that we were obliged to await its next return to perihelion in Jan. 1866 for further information relative to its physical condition. This return was looked forward to with much interest; as it was important to know what changes had occurred during the preceding 13 years in the relative position of the two portions so strangely rent asunder, as already narrated—whether they still travelled through space in company or not. That between 1846 and 1852 they had become, for all practical purposes, two complete comets, seemed indisputable; and in the sweeping Ephemerides issued from the *Nautical Almanac* office, by Mr. Hind, for facilitating their rediscovery in 1859, two independent sets of elements and positions were given.

It was calculated that the comet would have been seen in 1865–6 under very favourable circumstances, and search was systematically made for it at numerous European Observatories, but without success. Much disappointment was felt by astronomers: and startling as such a suggestion may appear[f], even the continued *existence* of the comet seemed so open to uncertainty that all hopes of seeing it again were given up.

At least one man, however, did not despair. M. Klinkerfues of Göttingen kept the subject before him, and as the result of his labours, he sent, on Nov. 30, 1872, to Pogson at Madras, a telegram as follows: "*Biela touched Earth on 27th: search near θ Centauri.*" The search was made, and *a* comet found, and observations of it were obtained on Dec. 2 and 3, 1872. Bad weather and the advance of twilight prevented further success[g]. Here the matter rests till 1879: it is however the opinion of Bruhns that the comet seen by Pogson could not possibly have been Biela's, but some other.

D'ARREST'S COMET,

No. 6.—On June 27, 1851, D'Arrest, at Leipzig, discovered a very faint telescopic comet in the constellation Pisces. Within a fortnight of its discovery the observations appeared irreconcileable with a parabolic orbit, and it was soon placed beyond a doubt that its true path was an ellipse. The comet was visible for more than 3 months; but notwithstanding this, the results of the calculations of the orbit were very discordant, and the predicted return of the comet in the winter of 1857–8 must be regarded rather in the light of a successful guess than anything else. Sir Thomas Maclear, at the Royal Observatory, Cape of Good Hope, was the only observer of this apparition.

M. Villarceau communicated to the Academy of Sciences at Paris, on July 22, 1861, an interesting memoir on the orbit of this comet, which may be usefully placed on record (in an epitomised form) as it will serve to give some insight into the nature of the mathematical investigations which the calculators of cometary orbits are called upon to conduct:—

[f] I assume that we are required to ignore certain alleged observations of "something" which formed a topic of discussion at several meetings of the Royal Astronomical Society, in the spring of 1866. (See *Month. Not.*, vol. xxvi. pp. 241 and 271.)

[g] *Month. Not.*, vol. xxxiii. p. 116. Dec. 1872.

The perturbations experienced by this comet are owing chiefly to the action of Jupiter, to which it is so near, that during the month of April of the present year [1861] its distance was only 0·36, or little more than *one-third* of the Earth's distance from the Sun. Before and after this epoch, Jupiter and the comet have continued, and will continue, so little distant from one another, as to produce the great perturbations to which the comet is at present subject.

From a table of the elements of the perturbations produced by Jupiter, Saturn, and Mars, in the interval between the appearance of the comet in 1857–8 and its return to its perihelion in 1864, M. Villarceau obtained the following results:—

(1) The longitude of the perihelion will have diminished 4° 35′ to Aug. 1863, and will remain sensibly stationary for about a year from that epoch. (2) The longitude of the node will have continually diminished to the amount of 2° 8′. (3) The inclination will have increased 1° 49′ to the middle of 1862, and will diminish 6′ during a year, continuing stationary during the year following. (4) The eccentricity, after having increased to the middle of 1860, will diminish rather quickly, and will remain stationary from 1863–5 to 1864–6. "But of all these perturbations," says M. Villarceau, "the most considerable are those of the mean motion and the mean anomaly. After having increased from 5″ to July, 1860 the mean motion diminishes 9″ in one year, and nearly 12″ in the year following, remaining stationary in the last year, and with a value 15″, 5″ less than at its origin. The perturbations of the mean anomaly, after having gradually increased till 1860, will increase rapidly till 1861, when they will amount to 10° 28′; and setting out from this, they will increase 9′, and in 1863 and 1864 they will have resumed the same value which they had in 1861."

The effect of the first of these perturbations will be to increase the time of the comet's revolution by about 69 days; and of the second, to hasten by 49 days the return of the comet to its perihelion in 1864. It will pass its perihelion on Feb. 26, whereas without the influence of these perturbations it would have passed it on April 15.

As was anticipated, the comet escaped notice altogether at its return to perihelion in 1864. But in 1870, astronomers were more fortunate, and were able to follow it for 4 months. Winnecke has pointed out that D'Arrest's comet is undoubtedly the faintest of all the known periodic comets [h].

Faye's Comet,

No. 7, was discovered by M. Faye, at the Paris Observatory, on Nov. 22, 1843, it being then in the constellation Orion. It exhibited a bright nucleus, with a short tail, but was never sufficiently brilliant to be seen by the unaided eye. That the comet's path was an ellipse seems to have been suspected independently by more than one observer. To Le Verrier, however, is due the

[h] *Ast. Nach.*, vol. lxxv. No. 1824. Oct. 12, 1870.

credit of having completely investigated its elements. That astronomer shewed that the comet came into our system at least as far back as the year 1747, when it suffered much perturbation from Jupiter[1]; and, further, that its next perihelion passage would occur on April 3, 1851.

It was rediscovered by Challis, at Cambridge, on Nov. 28, 1850. O. Struve described it, under the date of Jan. 24, 1851, as having a diameter of 24″. During the whole time it was observed it had scarcely any nucleus or tail. This comet returned in due course to perihelion on Sept. 12, 1858, having been detected 4 days previously by Bruhns, at Berlin. It was also seen in 1866 and 1873.

TUTTLE'S COMET,

No. 8, was detected by Méchain, on Jan. 9, 1790. It was only followed for a fortnight. On Jan. 11 Messier could see but a confused nebulosity, without any indications of a nucleus. It was not re-observed until its return at the commencement of 1858, on Jan. 4 of which year it was detected by H. P. Tuttle, at Harvard College Observatory, Cambridge, U.S. It returned again to perihelion in Nov. 1871, and is now accepted as a regular member of the group of short-period comets.

Short periods have also been assigned to the following comets; but too much uncertainty prevails with respect to them, to justify their being included with the foregoing[k]:—

Clausen (1743, i)	Blainpain (1819, v)
Burckhardt (1766, ii)	Peters (1846, vi)
Lexell (1770, i)	Tempel (1873, ii)
Pigott (1783)	Coggia (1873, vii)

[1] The intelligent reader may wonder why Jupiter is so constantly called to account as the great bugbear of these short-period comets. The reasons are two in number:—(1) The immense *mass* of Jupiter compared with that of any of the other planets; and (2) the fact that the aphelia of all these comets lie very close to the orbit of Jupiter; so that when at their greatest distance from the Sun, they are constantly liable to *rencontres*, more or less intimate, though by no means friendly, with the colossal planet. It is, moreover, an incidental indication of the potency of Jupiter's influence over comets, that so many short-period comets have periods amounting to between 5 and 6 years, being about the time occupied by Jupiter in traversing *half* its orbit.

[k] The reader will find a few brief particulars in the notes to the 1st catalogue, *post;* but for further information he must consult Hind's *Comets*, or Cooper's *Cometic Orbits*—two works which everybody interested in this branch of astronomy ought to possess.

In Class II. we have the following comets :—

Name.	Period.	Probable next Return.
	Years.	
1. Westphal (1852, iv)	67·77	1920
2. Pons (1812)..	70·68	1883
3. Di Vico (1846, iv)	73·25	1919
4. Olbers (1815)	74·05	1887
5. Brorsen (1847, v)	74·97	1922
6. Halley	76·78	1910

It has been suggested (I know not by whom) that 4 of the above may have originally constituted a single comet.

No. 6. The comet which has the most interesting pedigree is undoubtedly that which bears the name of our illustrious countryman Halley; and as its history will, moreover, serve to exemplify various remarks made in previous pages on the nature and appearance of comets, I cannot do better than give a summary of the said history from the time of the comet's last appearance, in 1835, back to the earliest ages. A few years after the advent of the celebrated comet of 1680, Sir I. Newton published his *Principia*, in which he applied to that body the general principles of physical investigation first promulgated in that work. He explained the method of determining, by geometrical construction, the visible portion of the path of a body of this kind, and invited astronomers to apply these principles to the various recorded comets. Such was the effect of the force of analogy upon the mind of the great philosopher, that, without awaiting the discovery of a periodic comet, he boldly assumed these bodies to be analogous to planets in their revolutions round the Sun. Startling as this theory might have seemed when first propounded, yet it was not long before it was fully substantiated. Halley, who was then a young man, undertook the labour of examining the circumstances attending all the comets previously recorded with a view to ascertain whether any, and, if so, which of them, appeared to follow the same path. Careful investigation soon proved that the orbits of the comets of 1531 and 1607 were similar, and that they were, in fact, the same as that followed by the comet of 1682, seen by

himself. He suspected therefore (and rightly too, as the sequel shewed) that the appearances at these 3 epochs were produced by the 3 successive returns of one and the same body, and that consequently its period was somewhere about 75½ years. There were nevertheless 2 circumstances which might be supposed to offer some difficulty, inasmuch as it appeared that the intervals between the successive returns were not precisely equal, and that the inclination of the orbit was not exactly the same in each case. Halley, however, "with a degree of sagacity which, considering the state of knowledge at the time, cannot fail to excite unqualified admiration, observed that it was natural to suppose that the same causes which disturbed the planetary motions would likewise act on comets;" in other words, that the attraction of the planets would exercise some influence on comets and their motions. The truth of this idea we have already seen exemplified in the case of the comet of 1770. In fine, Halley found that in the interval between 1607 and 1682 the comet passed so near Jupiter that its velocity must have been considerably increased, and its period consequently shortened; he was, therefore, induced to *predict* its return about the end of 1758 or the beginning of 1759. Although Halley did not survive to see his prediction fulfilled, yet, as the time drew near, great interest was manifested in the result, more especially as Clairaut had named April 13, 1759, as the day on which the perihelion passage would take place. It was not destined, however, that a professional astronomer should be the first[1] to detect the comet on its anticipated return; that honour was reserved for a farmer near Dresden, named Palitzch, who saw it on the night of Christmas-day, 1758. But few observations were made before the perihelion passage (on March 12), owing to the comet's proximity to the Sun; during the months of April and May, however, it was seen throughout Europe, although to the best advantage only in the Southern hemisphere. On May 5 it had a tail 47° long.

Previously to the last return of this comet, in 1835, numerous preparations were made to receive it. Early in that year Rosenberger, of Halle, published a memoir, in which he announced

[1] It was stated by Prof. R. Grant in a lecture at the Royal Institution in 1870, that Messier detected this comet at an early date, but was ordered to hold his tongue. I do not know what authority there is for this statement.

that the perihelion passage would take place on Nov. 11, though Damoiseau and Pontécoulant both fixed upon a somewhat earlier period.

Let us now see how far these expectations were realised. The comet was seen at Rome on Aug. 5; as it approached the Sun it gradually increased both in magnitude and brightness, but did not become visible to the naked eye till Sept. 20. On Oct. 19 the tail had attained a length of fully 30°. The comet was soon afterwards lost in the rays of the Sun, and passed through its perihelion on Nov. 15, or within 4 days of the time named by Rosenberger. It reappeared early in Jan. 1836, and was observed in the south of Europe and at the Cape till the middle of May, when it was finally lost to view, not to be seen again till the year 1910[m].

We have seen above that Halley traced his comet back to the year 1531; we must now, therefore, briefly review its probable history prior to that date, as made known by the labours of modern astronomers. Halley surmised that the great comet of 1456 was identical with the one observed by him in 1682, and Pingré converted Halley's suspicion into a certainty. The preceding return took place, as Laugier has shewn, in 1378, when the comet was observed both in Europe and China; but it does not appear to have been so bright in that year as in 1456. In Sept. 1301 a great comet is mentioned by nearly all the historians of the period. It was seen as far North as Iceland. It exhibited a bright and extensive tail, which stretched across a considerable part of the heavens. This was most likely Halley's comet. The previous apparition is not so well ascertained, but it most likely occurred in July 1223, when it is recorded in an ancient chronicle that a wonderful sign appeared in the heavens shortly before the death of Philip Augustus of France, of which event it was generally considered to be the precursor. It was only seen for 8 days. Although but little information is possessed about it, and that of a very vague character, yet it seems probable that this was Halley's comet. In April 1145 a great comet is mentioned by European historians, which is one of the most certain of our series of returns. In April 1066 an important comet became visible

[m] Drawings by Bessel will be found in the *Ast. Nach.*, vol. xiii. Nos. 300–2. Feb. 20, 1836.

which astonished Europe. It is minutely, though not very clearly, described in the Chinese annals; and the path there assigned to it is found to agree with elements which bear a great resemblance to those of Halley's comet. In England it was considered the forerunner of the victory of William of Normandy, and was looked upon with universal dread. It was equal to the Full Moon in size, and its train, at first small, increased to a wonderful length. Almost every historian and writer of the 11th century bears witness to the splendour of the comet of 1066, and there can be but little doubt that it was Halley's. Previous to this year the comet appeared in 989, 912, 837, 760, 684, 608, 530, 451, 373, 295, 218, 141, 66 A.D., and 11 B.C., all of which apparitions have been identified by Hind[n].

Concerning the comets belonging to Class III. it is not necessary to notice them further here; they will be found in the catalogue.

[n] *Month. Not.*, vol. x. p. 51. Jan. 1850.

CHAPTER III.

REMARKABLE COMETS.

The Great Comet of 1811.—*The Great Comet of* 1843.—*The Great Comet of* 1858.—*The Comet of* 1860 (iii).—*The Great Comet of* 1861.—*The Comet of* 1862 (iii).—*The Comet of* 1864 (ii).—*The Comet of* 1874 (iii).

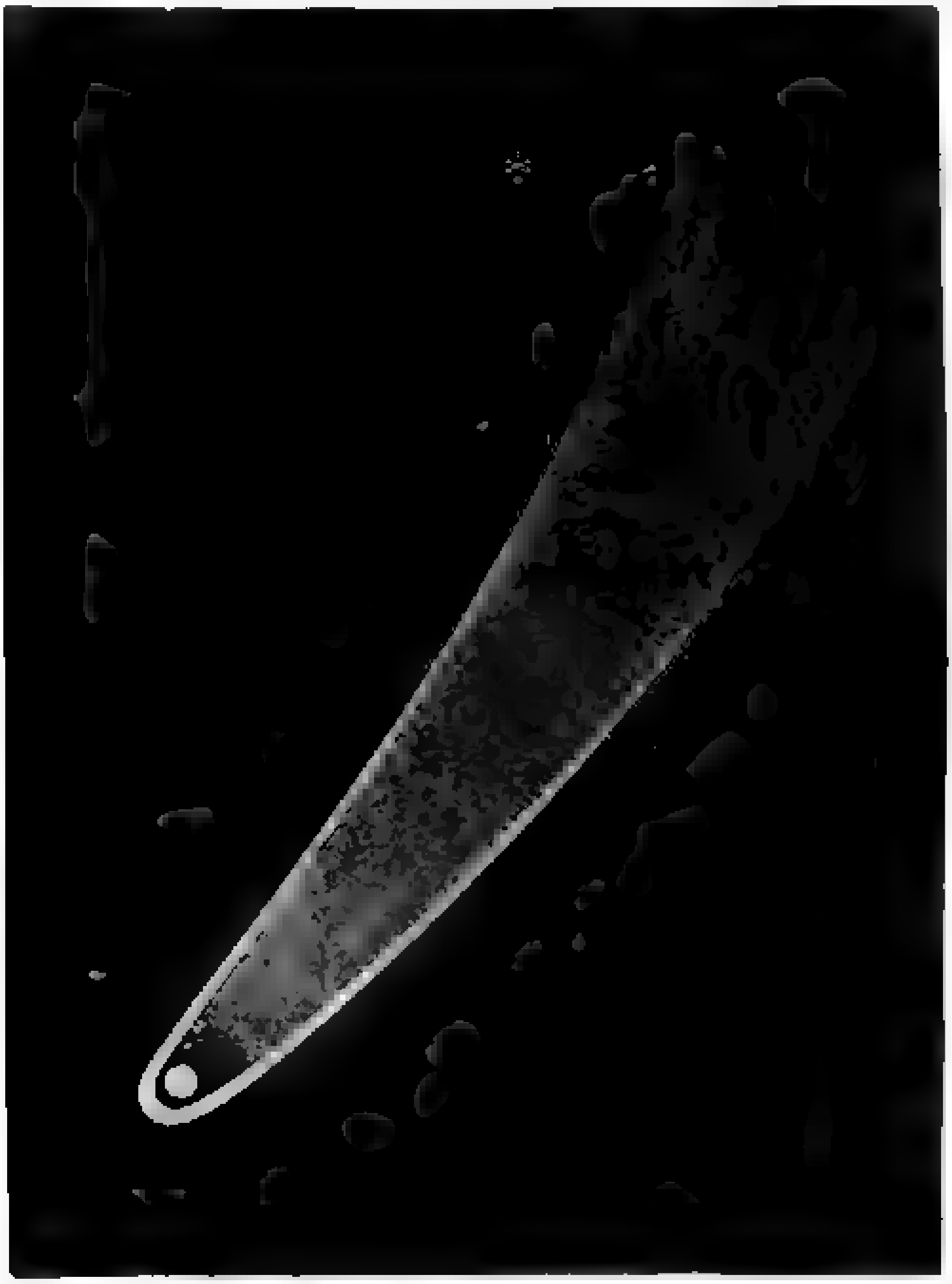
THE comets which might be included under the above head are so numerous as to make it impossible that all should receive proper attention. I must therefore limit myself to some few of the most interesting, premising that Grant includes the following comets under the designation "remarkable":—

1066	1531	1682	1823
1106	1556	1689	1835
1145	1577	1729	1843
1265	1607	1744	1858
1378	1618	1759	1861
1402	1661	1769	
1456	1680	1811	

The Comet of 1811 (i) is one of the most celebrated of modern times. It was discovered by Flaugergues, at Viviers, on March 26, 1811, and was last seen by Wisniewski at Neu-Tscherkask, on Aug. 17, 1812. In the autumnal months of 1811 it shone very conspicuously, and its great Northern declination caused it to remain visible throughout the night for many weeks. The extreme length of the tail at the beginning of October was about 25°, and its breadth about 6°. Sir W. Herschel paid particular attention to this comet, and the observations which he made are very valuable. He states that it had a well-defined nucleus, the diameter of which he found by careful measurement to be 428 miles; further, that the nucleus was of a ruddy hue, though the surrounding nebulosity

had a bluish-green tinge [a]. This comet undoubtedly is a periodical one. Argelander, whose investigation of the orbit is the most complete that has been carried out, assigns to it a period of 3065 years, subject to an uncertainty of only 43 years [b]. The aphelion

Fig. 107.



THE GREAT COMET OF 1811.

distance is 14 times that of Neptune, or, more exactly, 40,121,000,000 miles!

The Comet of 1843 (i) was one of the finest that has appeared during the present century. It was first seen in the Southern

[a] *Phil. Trans.*, vol cii. pp. 118, 119, 121.
[b] *Berlin. Ast. Jahrbuch* 1825, p. 250.

Fig. 108.

Plate XIV.

DONATI'S COMET: October 5, 1858.

(Drawn by Pape.)

hemisphere towards the end of the month of February, and during the first fortnight in March it shone with great brilliancy. It was not visible in England until after the 15th, when its splendour was much diminished; but the suddenness with which it made its appearance added not a little to the interest which it excited. The general length of the tail during March was about 40°, and its breadth about 1°. The orbit of this comet is remarkable for its small perihelion distance, which did not exceed, according to the

Fig. 109.

DONATI'S COMET, 1858, PASSING ARCTURUS ON OCT. 5.

most reliable calculations, 538,000 miles; and the immense velocity of the comet in its orbit, when near the perihelion, occasioned some extraordinary peculiarities. Thus between Feb. 27 and 28 it described upon its orbit an arc of 292°. Supposing it to revolve in an ellipse, this would leave only 68° to be described during the time which elapses before its next return to perihelion.

It has been thought by some that this comet was identical with those of 1668 and 1689, but so little is known *for certain* about this latter that we are not yet in a position to admit or deny

Fig. 110. Plate XV.

DONATI'S COMET: October 9, 1858.

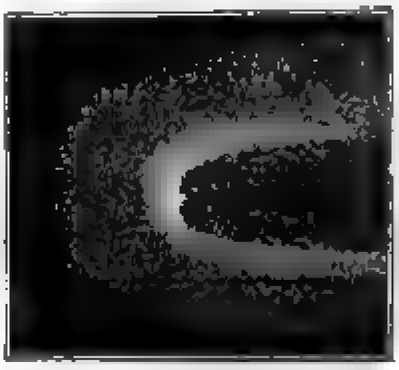
(Drawn by Pape.)

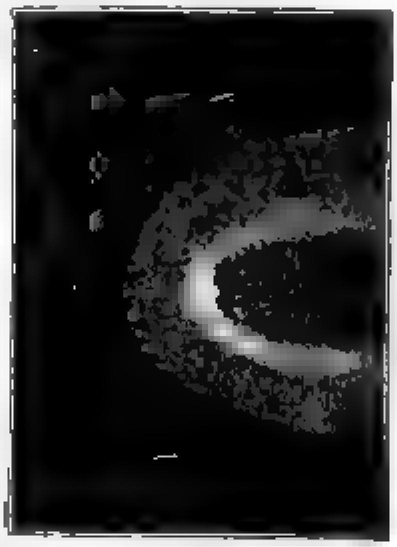
the identity of the 3 bodies. In the work to which reference is made in the note the question is discussed with great ability [c].

The Comet of 1858 (vi). On June 2 in that year, Dr. G. B. Donati, at Florence, descried a faint nebulosity slowly advancing towards the North, and near the star λ Leonis. Owing to its immense distance from the Earth (240,000,000 miles), great difficulty was experienced in laying down its orbit. By the middle of August, however, its future course and the great increase in its brightness which would take place in September and October were clearly foreseen. Up to this time (middle of August) it had remained a faint object, not discernible by the unaided eye. It was distinguished from ordinary telescopic comets only by the extreme slowness of its motion (in singular contrast to its subsequent career), and by the vivid light of its nucleus: "the latter peculiarity was of itself prophetic of a splendid destiny." Traces of a tail were noticed on Aug. 20, and on Aug. 29 the comet was faintly perceptible to the naked eye; for a few weeks it occupied a northern position in the heavens, and it was therefore seen both in the morning and evening. On Sept. 6 a slight curvature of the tail was noticed, which subsequently became one of its most interesting features. On Sept. 17 the head equalled in brightness a star of the 2nd magnitude, the length of the tail being 4°. The comet passed through perihelion on Sept. 29, and was at its least distance from the Earth on Oct. 10. Its rapid passage to the Southern hemisphere rendered it invisible in Europe after the end of October, but it was followed at the Santiago-de-Chili and Cape of Good Hope Observatories for some months afterwards, and was last seen by Sir T. Maclear at the latter place on March 4, 1859.

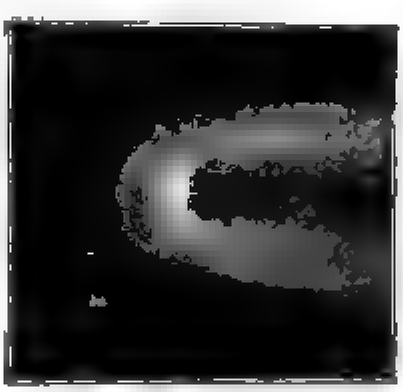
"Its early discovery enabled astronomers, while it was yet scarcely distinguishable in the telescope, to predict, some months in advance, the more prominent particulars of its approaching apparition, which was thus observed with all the advantage of previous preparation and anticipation. The perihelion passage occurred at the most favourable moment for presenting the comet to good advantage. When nearest the Earth, the direction of the tail was nearly perpendicular to the line of vision, so that its proportions were seen without foreshortening. Its situation in

[c] E. J. Cooper, *Cometic Orbits*, pp. 159-69.


September 29. (*Pape.*)


October 12. (*Pape.*)


Anon.


September 12. (*Pape.*)


October 6. *Pape.*

DONATI'S COMET, 1858: Views of the Coma.

the latter part of its course afforded also a fair sight of the curvature of the train, which seems to have been exhibited with unusual distinctness, contributing greatly to the impressive effect of a full-length view."

This comet, though surpassed by many others in size, has not often been equalled in the intense brilliancy of the nucleus, which the absence of the Moon, in the early part of October, permitted to be seen to the very best advantage. There is no doubt that the comet of Donati revolves in an elliptic orbit with a period of about 2000 years (Stampfer, 2138^y; Löwy, 2040^y; Von Asten, 1879^y).

The following is a table of the dimensions of the comet's nucleus and tail, at the undermentioned dates[d]:—

Date.		Diameter of Nucleus.		Length of Tail.	
1858.		"	Miles.	°	Miles.
July	19	5	= 5600		..
Aug.	30	6	= 4660	2	= 14,000,000
Sept.	8	3	= 1980	4	= 16,000,000
„	12	..		6	= 19,000,000
„	23	3	= 1280	5	= 12,000,000
„	25	..		11	= 17,000,000
„	27	..		13	= 18,000,000
„	28	..		19	= 26,000,000
„	30	..		22	= 26,000,000
Oct.	2	..		25	= 27,000,000
„	5	1·5	= 400	33	= 33,000,000
„	6	3·0	= 800	50	= 45,000,000
„	8	4·4	= 1120	50	= 43,000,000
„	10	2·5	= 630	60	= 51,000,000
„	12	..		45	= 39,000,000

The Comet of 1860 (iii). In the latter end of June 1860, a comet of considerable brilliancy suddenly made its appearance in the Northern circumpolar regions. Bad weather prevented it from being generally observed in England, but in the south of Europe it was well seen; copies of some drawings made at Rome are annexed.

[d] G. P. Bond, *Math. Month. Mag.* Boston, U.S., Nov. and Dec. 1858. Mr. Bond subsequently published a magnificent memoir on this comet in vol. iii. of the *Annals of the Harvard College Observatory.* Cambridge, Mass., 1862.

June 26

June 28.

June 30.

July 1.

July 6

July 8.

COMET III: 1860.

(*Drawn by Cappelletti and Rosa.*)

Few comets created greater sensation than the Great Comet of 1861 (ii. of that year). It was discovered by Mr. J. Tebbutt, an amateur observer in New South Wales, on May 13, previous to its perihelion passage, which took place on June 11. Passing from the Southern hemisphere into the Northern, it became visible in this country on June 29, though it was not generally seen till the next evening. So many accounts of it were published that selection is difficult, but the following pages will be found to contain an epitome of the most noticeable features[e].

Sir J. Herschel observed it in Kent. He says :—

"The comet, which was first noticed here on *Saturday* night, June 29, by a resident in the village of Hawkhurst (who informs me that his attention was drawn to it by its being taken by some of his family for the Moon rising), became conspicuously visible on the 30th, when I first observed it. It then far exceeded in brightness any comet I have before observed, those of 1811 and the recent splendid one of 1858 not excepted. Its total light certainly far surpassed that of any fixed star or planet, except perhaps Venus at its maximum. The tail extended from its then position, about 8 or 10° above the horizon, to within 10 or 12° of the Pole-star, and was therefore about 30° in length. Its greatest breadth, which diminished rapidly in receding from the head, might be about 5°. Viewed through a good achromatic, by Peter Dollond, of 2¾-inches aperture and 4-feet focal length, it exhibited a very condensed central light, which might fairly be called a nucleus; but, in its then low situation, no other physical peculiarities could be observed. On the 1st instant it was seen early in the evening, but before I could bring a telescope to bear on it clouds intervened, and continued till morning twilight. On the 2nd (Tuesday), being now much better situated for observation, and the night being clear, its appearance at midnight was truly magnificent. The tail, considerably diminished in breadth, had shot out to an extravagant length, extending from the place of the head above o of the Great Bear at least to π and ρ Herculis; that is to say, about 72°, and perhaps somewhat further. It exhibited no bifurcation or lateral offsets, and no curvature like that of the comet of 1858, but appeared rather as a narrow prolongation of the Northern side of the broader portion near the comet than as a thinning off of the latter along a central axis, thus imparting an unsymmetrical aspect to the whole phenomenon.

"Viewed through a 7-feet Newtonian reflector of 6 inches aperture the nucleus was uncommonly vivid, and was concentrated in a dense pellet of not more than 4″ or 5″ in diameter (about 315 miles). It was round, and so very little *woolly* that it might *almost* have been taken for a small planet seen through a dense fog; still so far from *sharp* definition as to preclude any idea of its being a solid body. No sparkling or star-light point could, however, be discerned in *its* centre with the power used (96), nor any separation by a darker interval between the nucleus and the cometic envelope. The gradation of light, though rapid, was continuous. Neither on this occasion was there any *unequivocal* appearance of that sort of fan or sector of light which has been noticed on so many former ones.

[e] By far the most complete account is that by the Rev. T. W. Webb in the *Month. Not.*, vol. xxii. p. 305. 1862.

Figs. 122–125. **Plate XVIII.**

July 8. (*Webb.*)

July 2. (*Brodie.*)

July 2. (*Brodie.*)

July 2. (*Chambers.*)

THE GREAT COMET OF 1861.

"The appearance of the 3rd was nearly similar, but on the 4th the fan, though feebly, was yet certainly perceived; and on the 5th was very distinctly visible. It consisted, however, not in any vividly radiating jet of light from the nucleus of any well-defined form, but in a crescent-shaped cap formed by a very delicately graduated condensation of the light on the side towards the Sun, connected with the nucleus, and what may be termed the *coma* (or spherical haze immediately surrounding it), by an equally delicate graduation of light, very evidently superior in intensity to that on the opposite side. Having no micrometer attached, I could only estimate the distance of the brightest portion of this crescent from the nucleus at about 7′ or 8′, corresponding at the then distance of the comet to about 35,000 miles. On the 4th (Thursday) the tail (preserving all the characters already described on the 2nd) passed through α Draconis and τ Herculis, nearly over η and ϵ Herculis, and was traceable, though with difficulty, almost up to α Ophiuchi, giving a total length of 80°. The northern edge of the tail, from α Draconis onwards, was perfectly straight,—not in the least curved,—which, of course, must be understood with reference to a great circle of the heavens.

"Viewed, on the 5th, through a doubly refracting prism well achromatised, no certain indication of polarisation in the light of the nucleus and head of the comet could be perceived. The two images were distinctly separated, and revolved round each other with the rotation of the prism without at least any marked alternating difference of brightness. Calculating on Mr. Hind's data, the angle between the Sun and Earth and the comet must then have been 104°, giving an angle of incidence equal to 52°, and obliquity 38°, for a ray supposed to reach the eye *after a single* reflection from the cometic matter. This is not an angle unfavourable to polarisation, but the reverse. At 66° of elongation from the Sun (which was that of the comet on the occasion in question), the blue light of the sky is very considerably polarised. The constitution of the comet, therefore, is analogous to that of a cloud; the light reflected from which, as is well known, at that (or any other) angle of elongation from the Sun, exhibits no signs of polarity."

Hind stated that he thought it not only possible, but even probable, that in the course of Sunday, June 30, the Earth passed through the tail of the comet at a distance of perhaps two-thirds of its length from the nucleus. The head of the comet was in the ecliptic at 6 P.M. on June 28, at a distance from the Earth's orbit of 13,600,000 miles on the inside, its longitude, as seen from the Sun, being 279° 1′. The Earth at that moment was 2° 4′ behind that point, but would arrive there soon after 10 P.M. on Sunday, June 30. The tail of a comet is seldom an exact prolongation of the radius vector, or line joining the nucleus with the Sun; towards the extremity it is almost invariably curved; or, in other words, the matter composing it lags behind what would be its situation if it travelled with the same velocity as the nucleus. Judging from the amount of curvature on the 30th, and the direction of the comet's motion, Hind thought that the Earth very

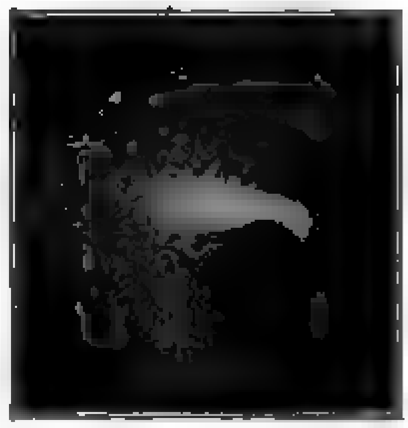
probably encountered the tail in the early part of that day, or, at any rate, that it was certainly in a region which had been swept over by the cometary matter but a short time previously.

In connexion with this subject, he added that on the evening of June 30, while the comet was so conspicuous in the northern heavens, there was a peculiar phosphorescence or illumination of the sky, which he attributed at the time to an auroral glare; it was remarked by other persons as something unusual, and, considering how near we must have been on that evening to the tail of the comet, it may perhaps be a point worthy of consideration whether such an effect might not be attributable to this proximity. If a similar illumination of the heavens had been remarked generally on the Earth's surface it would have been a very significant fact.

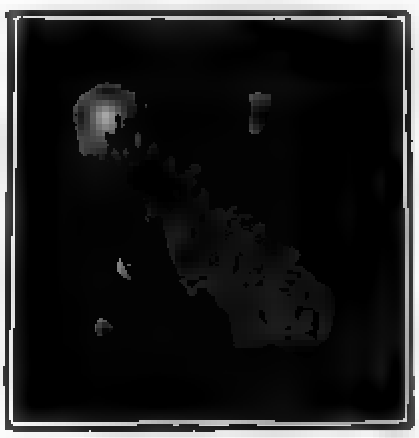
Mr. Lowe, of Highfield House, confirmed Mr. Hind's statement of the peculiar appearance of the heavens on June 30. The sky, he says, had a yellow auroral glare-like look, and the Sun, though shining, gave but feeble light. The comet was plainly visible at a quarter to 8 o'clock (during sunshine), while on subsequent evenings it was not seen till an hour later. In confirmation of this, he adds that in the Parish Church the vicar had the pulpit candles lighted at 7 o'clock, which proves that a sensation of darkness was felt even while the Sun was shining. Though he was not aware that the comet's tail was surrounding our globe, yet he was so struck by the singularity of the appearance, that he recorded in his day-book the following remark:—"A singular yellow phosphorescent glare, very like diffused Aurora Borealis, yet, being daylight, such Aurora would scarcely be noticeable." The comet itself, he states, had a much more hazy appearance than at any time after that evening.

De La Rue attempted to photograph the comet. After 3 minutes' exposure in the focus of his 13-inch reflector the comet had left no impression upon a sensitized collodion plate, although a neighbouring star, π Ursæ Majoris—close to which the comet passed on the night of the 2nd (Tuesday)—left its impression twice over, from a slight disturbance of the instrument. De La Rue also, at that time, fastened a portrait camera upon the tube of his telescope, and, with the clock motion in action, exposed a collodion plate for 15 minutes to the open view of the comet with-

Aug. 7.

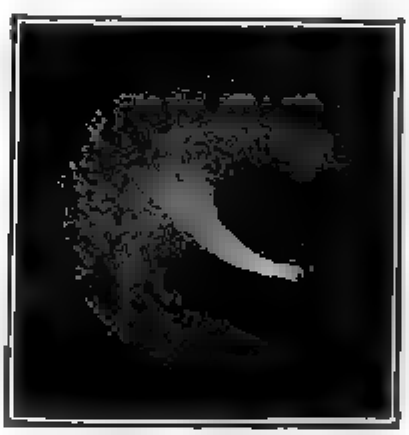


Aug. 18.

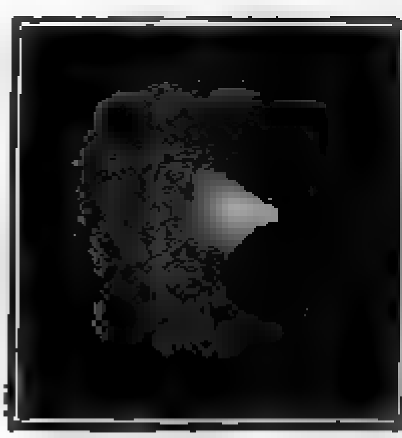


Aug. 18.

Aug. 19.



Aug. 22.



Aug. 29.

COMET III, 1862.

(*Drawn by Challis.*)

out any other effect than the general blackening of the surface by the skylight, together with impressions of several fixed stars in the neighbourhood.

Of the polarisation of the light of the comet, M. Secchi says:—

"The most interesting fact I observed is this: the polarisation of the light of the comet's tail and of the rays near the nucleus, was very strong, and one could even distinguish it with the band polariscope; but the nucleus presented no trace of polarisation, not even with Arago's polariscope with double coloured image. On the contrary, on the evenings of July 3, and following days, the nucleus presented decided indications, in spite of its extreme smallness, which, on the evening of July 7, was found to be hardly 1″.

"I think this a fact of great importance, for it seems that the nucleus on the former days shone by its own light, perhaps by reason of the incandescence to which it had been brought by its close proximity to the Sun.

"During the following days the tail has been constantly diminishing, but it is remarkable that it has always passed near to α Herculis, and that it reached to the Milky Way up to July 6. It would seem that the two tails were nearly independent, and that on July 5 the length and straightness had gone off from the large one, and that this bent itself to the southern side. Last night (July 7) the long train was hardly perceptible. The light was polarised in the plane of the tail."

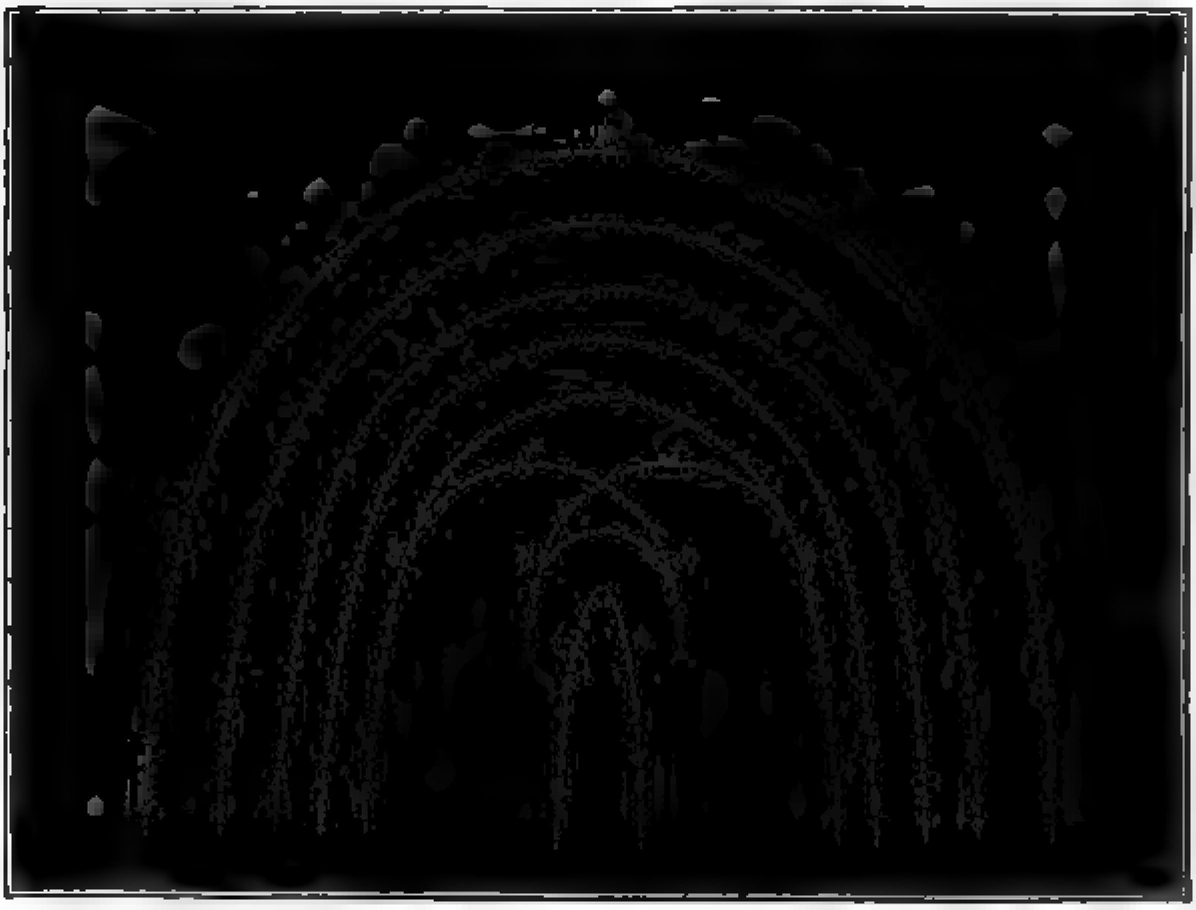
Observations on the polarisation of the light of the comet were also made by M. Poey, at Passy. This gentleman observed the polarisation in Donati's comet at Havannah in 1858, in which case the light was polarised in a plane passing through the Sun the comet and the observer; but, in the case of the present comet, "the plane of polarisation seemed to pass sensibly perpendicular to the axis of the tail," which, he thinks, may have been owing to atmospheric refraction.

The comet of 1862 (iii), though not one of first-class brilliancy, was nevertheless a very interesting object, particularly on account of the fact that a jet of light, frequently altering in form, was observed for a long time to emanate from its nucleus. Annexed are some views drawn by the Rev. J. Challis of Cambridge. This comet had a tail, which, on Aug. 27, was 20° long.

The comet of 1864 (ii), visible in August, had a head unusually large, scarcely less than ½° in diameter. To the naked eye it resembled on the 4th of that month a dull blurred star of the 3rd magnitude, but in the telescope it appeared as a circular mass of nebulous matter with a central condensation very similar to the well-known planetary nebula in Virgo. There was a faint tail, but it presented no special feature of interest.

The comet of 1874 (iii), discovered by Coggia at Marseilles on April 17, was one of considerable interest. The drawing from which the frontispiece to this volume has been engraved (and of which figure 133 is a skeleton outline) was made with an achromatic telescope of $8\frac{1}{4}$ inches aperture and $11\frac{1}{2}$ feet focal length, on July 13, the most favourable night during its appearance, when its position in the heavens, its contiguity to the Earth, and the absence of twilight are jointly taken into consideration. The Southward motion of the comet was so rapid that on July 14 the presence of

Fig. 132.



Coggia's Comet of 1874.
Skeleton outline on July 13. (*Brodie.*)

a, g, a. Undefined outline of nebulous head.
b, c, b. Fairly defined outline of second envelope.
d, d. Sharply defined outline of first envelope, semicircular, and very bright.
e, e. Very sharply defined clear dark space between bifurcation of tail, free from nebulosity.
f, f. Singular eccentric envelopes, sharply defined, fading away at and into *b b*. The centres of those envelopes were at *d*.
g, c. Between these two points several envelopes concentric with *d d* were traceable.

twilight greatly interfered with the details shewn in the drawing. The following description is from the pen of Mr. F. Brodie:—

"The head of the comet presented the great peculiarity of having two eccentric envelopes in addition to the ordinary bright envelope immediately surrounding the

nucleus. This first envelope was a bright and sharply defined semicircle surrounding the nucleus: the two eccentric envelopes were nearly as bright, and also very sharply defined, also semicircular, having their centres placed (about) on the edge of the first envelope, and intersecting each other. The second centrical envelope just embraced both these eccentric envelopes, and was about half the width of the nebulous head of the comet. Between this second envelope and the ill-defined outline of the head (that is, between *c* and *g*) there were faintly marked outlines of other concentric envelopes. The nucleus, which, according to Hind, was 4000 miles in diameter, appeared to be somewhat flattened on the side opposite to the Sun. From this side also the head of the comet divided itself into two distinct parts forming the commencement of the tail: for some distance this bifurcation was remarkably sharply defined, suggesting an intense repulsive force acting upon the nucleus of the comet; and the space enclosed between this bifurcation was strikingly free from nebulous matter, until at some little distance away from the nucleus the sharp definition faded into the general nebulosity of the tail."

The following remarks[a] on this comet are by two French observers, MM. Wolf and Rayet:—

"After having maintained for many days a great sameness of form, on June 22 a series of changes in the shape of the head of the comet commenced. On that day the comet, viewed with a Foucault telescope of 40 centimetres, appeared to be enclosed in the interior of a very elongated parabola. Starting from the nucleus, which was placed as it were at the focus of the curve, the brightness decreased gradually towards the summit: but in the interior of the parabola the diminution of the brightness was sudden, and the boundary-line exhibited another parabola a little more open than the first, and having at its own summit the brilliant nucleus itself. The outline of the parabola which passed through the nucleus was prolonged so as to form the lateral boundaries of the tail, the edges of which were well defined and were much brighter than the interior parts. This tail had then the appearance of a luminous envelope hollow in the inside. The nucleus was always very sharp. On July 1 the general form of the comet remained the same; it appeared always to possess a parabolic outline at its exterior edge. The nucleus however jutted out into the interior of the second parabola, and the opposite margins of the tail were not strictly symmetrical. The West side, that is to say the side which had the greatest R. A., was very sensibly brighter than the other. . . . From July 5, the want of symmetry spoken of above became more and more marked, and near the head the decrease of the brightness became less regular. On July 7, the contrast between the two branches was striking, the Western branch of the tail being about twice as bright as the Eastern. At the same time the nucleus appeared to be becoming diffused, and it seemed to fade away in the direction of the head of the comet, although still sharply defined on the side nearest the tail; one could not fail to remark its resemblance to an opened fan. . . . Our last observation of the comet was made on July 14 at 9.30 P.M.: important changes in the aspect of the head had manifested themselves. The fan of light had disappeared on the West side, and was replaced by a long spur of light which was traceable for a considerable distance across the head; on the West side the remnant of the fan terminated abruptly, and the boundary-line there made but a small angle

[a] Translated for this work from Guillemin's *Comètes*, p. 293.

with the main axis of the comet. On this same occasion two rays of light were visible —two jets as they might be deemed—thrown forwards, the one to the right and the other to the left; these luminous rays seemed to have their origin at the edge of the fan of which they formed a sort of prolongation. The ray which pointed towards the East projected well forwards, and being bent round towards the tail soon reached the preceding edge of the comet; it was faint and hardly surpassed the nebulosity in brilliancy. The ray projected towards the West was much more brilliant, and was similarly bent round towards the tail, which it assisted in providing with a bright exterior edge."

On July 13, the comet was 35,000,000 miles from the Earth, and although it approached to within 26,000,000 miles on July 21, it was then too nearly in conjunction with the Sun to be seen. The tail was calculated by Hind to have increased in actual length from 4,000,000 miles on July 3 to 25,000,000 miles on July 19, augmenting in angular length from 4° to upwards of 43°. On the evening on which Mr. Brodie's sketch was taken the tail appeared to be rather arched towards the western horizon, and could be traced by the naked eye for nearly 20°. This comet certainly revolves in an elliptic orbit, but the period is long: probably 10,000 years or so, the semi-axis major being upwards of 400 times the Earth's mean distance from the Sun.

CHAPTER IV.

COMETARY STATISTICS.

Dimensions of the Nuclei of Comets.—Of the Comæ.—Comets contract and expand on approaching to, and receding from, the Sun.—Exemplified by Encke's in 1838.—Lengths of the Tails of Comets.—Dimensions of Cometary orbits.—Periods of Comets.—Number of Comets recorded.—Duration of visibility of Comets.

ALTHOUGH I have hitherto refrained as much as possible from embarrassing the reader with any tedious display of figures, yet I must now say something about the real dimensions of comets, and of the orbits they describe: also about their number, and duration of visibility.

The following are the real diameters*, in English miles, of the nuclei of some of the comets which have been satisfactorily measured within the last hundred years:—

Examples of a Large Nucleus.	Miles.	*Examples of a Small Nucleus.*	Miles.
The Comet of 1845 (iii)	8000	The Comet of 1798 (i)	28
Donati's Comet, 1858	5600	The Comet of 1806	30
The Comet of 1815	5300	The Comet of 1798 (ii)	125
The Comet of 1825 (iv)	5100	The Comet of 1811 (i)	428

The dimensions of the *comæ*, or heads, of comets also vary greatly, thus:—

Examples of a Large Coma.	Miles.	*Examples of a Small Coma.*	Miles.
The Comet of 1811 (i) ..	1,125,000	The Comet of 1847 (v)	18,000
Halley's Comet, 1835 ..	357,000	The Comet of 1847 (i)	25,500
Encke's Comet, 1828 ..	312,000	The Comet of 1849 (ii)	51,000

It should be remarked that the real dimensions of comets are found to vary greatly at different periods of the same apparition,

* All the dimensions in miles in this chapter depend on the old value of the Sun's parallax. They need to be augmented by about $\frac{1}{30}$ to accommodate them to what is now regarded as the probable amount of the Sun's parallax. This has not however been done because this value still continues somewhat uncertain.

for there is no doubt that many of these bodies *contract* as they approach the Sun, and expand again as they recede from it—a fact first noticed by Kepler in the case of the great comet of 1618.

The following measurements of Encke's comet in 1838, when approaching the Sun, will illustrate this:—

Date.	Diameter.	Distance from ☉
1838.	Miles.	
Oct 9	281,000	1·42
„ 25	120,500	1·19
Nov. 6	79,000	1·00
„ 13	74,000	0·88
„ 16	63,000	0·83
„ 20	55,500	0·76
„ 23	38,500	0·71
„ 24	30,000	0·69
Dec. 12	6,600	0·39
„ 14	5,400	0·36
„ 16	4,250	0·35
„ 17	3,000	0·34

The tails of comets, more especially of those visible to the naked eye, are often of stupendous length, as the following table will shew:—

	Greatest Length.		Miles.
The Comet of 1744	24°	=	19,000,000
The Comet of 1860 (iii)	15	=	22,000,000
The Comet of 1861 (ii)	105	=	24,000,000
The Comet of 1769	97	=	40,000,000
The Comet of 1858 (vi)	50	=	42,000,000
The Great Comet of 1618	104	=	50,000,000
The Comet of 1680	60	=	100,000,000
The Comet of 1811 (i)	25	=	100,000,000
The Comet of 1811 (ii)		=	130,000,000
The Comet of 1843 (i)	65	=	200,000,000

Cometary orbits are usually of immense extent. Thus:—

1. *As to Perihelion Distance.*

Greatest Known.	Miles.	*Least Known.*	Miles.
The Comet of 1729 ..	383,800,000	The Comet of 1843 (i) ..	538,000

2. *As to Aphelion Distance.*

Greatest Known.	Miles.	*Least Known.*	Miles.
The Comet of 1844 (ii)	406,130,000,000	The Comet of Encke ..	388,550,000

We have already seen that the period of the shortest comet yet known is but little more than 3 years: this is in striking contrast to the periods exhibited in the following table which are however so vast as to deserve little reliance:—

	Years.
The Comet of 1744	122,683
The Comet of 1844 (ii)	102,050
The Comet of 1780 (i)	75,314
The Comet of 1680	15,864
The Comet of 1847 (iii)	13,918
The Comet of 1840 (ii)	13,864

TABLE OF NUMBER OF COMETS RECORDED.

Period.	Comets Observed.	Orbits Calculated.	Comets Identified.
Before A.D.	78	4	1
Century 0—100	22	1	1
101—200	22	2	1
201—300	39	3	2
301—400	22	0	1
401—500	19	1	1
501—600	25	4	1
601—700	29	0	2
701—800	15	2	1
801—900	40	1	0
901—1000	29	2	3
1001—1100	36	4	2
1101—1200	27	0	1
1201—1300	28	3	3
1301—1400	34	7	3
1401—1500	43	10	1
1501—1600	38	13	4
1601—1700	31	20	5
1701—1800	70	64	8
1801—1875 (December)	204	188	52
	851	329	93

From the earliest period up to the present time, the number of comets of which there is any trustworthy record is about 850; but as it is only within the last 100 years that optical assistance has been made generally available in a systematic search for them, the real number of those that have appeared is probably not less than 4000 or 5000, especially when we consider that there have doubtless been many, visible only in the Southern hemisphere.

Comets remain visible for periods varying from a few days to more than a year, but the most usual time is 2 or 3 months. Much depends on the apparent position of the comet with respect to the Earth and the Sun, and much on its own intrinsic lustre. Among the comets which remained longest in sight, are the following:—

	Months.
The Comet of 1811 (i)	17
The Comet of 1825 (iv)	12
The Comet of 1861 (ii)	12
The Comet of 1835 (iii), (Halley's)	9½
The Comet of 1847 (iv)	9½
The Comet of 1858 (vi)	9
The Comet of 1844 (ii)	8
The Comet of 1847 (ii)	8

There are some few comets which have only been seen on one or two occasions, unfavourable weather preventing more extended observation of them.

CHAPTER V.

HISTORICAL NOTICES.

Opinions of the Ancients on the nature of Comets.—Superstitious notions associated with them.—Extracts from ancient Chronicles.—Pope Calixtus III and the Comet of 1456.—Extracts from the writings of English authors of the 16th and 17th centuries.—Napoleon and the Comet of 1769.—Supposed allusions in the Bible to Comets.—Conclusion.

GOING back to the early ages of the world, we find that the Chaldæans considered comets to be permanent bodies analogous to planets, but revolving round the Sun in orbits so much more extensive, that they were therefore only visible when near the Earth. This opinion, which, by the by, is the earliest hint that we have of the existence of periodical comets, was also held by philosophers of the Pythagorean school. Yet Aristotle, who records this, insists that comets are merely mundane exhalations, carried up into the atmosphere, and there ignited.

Anaxagoras, Apollonius, Democritus, and Zeno considered that these bodies were aggregations of many small planets.

It is a somewhat remarkable fact, that Ptolemy, so celebrated for his varied astronomical attainments, should nowhere have made any mention of comets; his omission is, however, atoned for by Pliny, who seems to have paid much attention to them. He enumerates 12 kinds, each class receiving its name from some physical peculiarity of the objects belonging to it.

Seneca considered that comets must be above [beyond] the Moon, and he judged from their rising and setting, that they had something in common with the stars.

Paracelsus gravely insisted that comets were celestial messengers, sent to foretell good or bad events—an idea which, even in the

present day, has by no means died out. The ancient Romans did not trouble themselves much about astral phenomena; they nevertheless looked upon the comet of 43 B.C. as a celestial chariot carrying away the soul of Julius Cæsar, who had been assassinated shortly before it made its appearance.

In an ancient Norman Chronicle there occurs a curious exposition of the divine right of William I. to invade England:—"How a star with 3 long tails appeared in the sky; how the learned declared that stars only appeared when a kingdom wanted a king, and how the said star was called a comette." Another old chronicler, speaking of the year 1065, says:—"Soon after [the death of Henry, King of France, by poison], a comet—a star, denoting, as they say, change in kingdoms—appeared, trailing its extended and fiery train along the sky. Wherefore, a certain monk of our monastery, by name Elmer, bowing down with terror at the sight of the brilliant star, wisely exclaimed, 'Thou art come! a matter of lamentation to many a mother art thou come. I have seen thee long since; but I now behold thee much more terrible, threatening to hurl destruction on this country[a].'"

The superstitious dread in which comets were held during the Middle Ages is well exemplified in the case of the comet of 1456 (Halley's). We find that the then Pope, Calixtus III, ordered the Church bells to be rung daily at noon, and extra *Ave Marias* to be repeated by everybody. Whilst the comet was still visible, Hunniades, the Papal general, gained an advantage over Mahomet, and compelled him to raise the siege of Belgrade, the remembrance of which the Pope preserved by ordering the Festival of the Transfiguration to be scrupulously observed throughout Christendom. "Thus was established the custom, which still exists in Romish countries, of ringing the bells at noon; and perhaps it is from this circumstance that the well-known cakes made of sliced nuts and honey, sold at the Church-doors in Italy on Saints' days, are called *comete*[b]."

Leonard Digges says that "comets signify corruptions of the ayre. They are signs of Earthquakes, of warres, of chaungyng

[a] Will. Malmes., *Hist. Nov.*, iii. cap. 13.

[b] Smyth, *Cycle*, vol. i. p. 231. A friend suggests a derivation which certainly appears much more rational; namely, *comedo*, to eat.

of kingdomes, great dearth of corne, yea a common death of man and beast[c]."

One John Gadbury says that "Experience is an eminent evidence, that a comet like a sword, portendeth war; and an hairy comet, or a comet with a beard, denoteth the death of kings." He also gives us a register of cometary announcements for upwards of 600 years, and adds in large Roman capitals, "as if God and nature intended by comets to ring the knells of princes, esteeming bells in Churches upon Earth not sacred enough for such illustrious and eminent performances."

A great English poet says:—

> "Satan stood
> Unterrified, and like a comet burned,
> That fires the length of Ophiuchus huge
> In th' Arctic sky, and from its horrid hair
> Shakes pestilence and war[d]."

The last comet employed in an astrological character was that of 1769, which Napoleon I. looked upon as his protecting *génie*. Indeed, as late as 1808 Messier published a work on it, of which the title is given below[e].

It would be quite impossible to mention the cometary theories which have been advanced since the introduction of telescopic observation. Some of the more important will be found in Grant's *History*, to which the reader is referred.

During the visibility of Donati's comet in 1858, the question was mooted whether the Bible contained any reference to these objects: the following passages were adduced in support of the idea:—

1. In *Leviticus* xvii. 7 it is said, "They shall no more offer their sacrifices unto Seirim," or Shoirim, which is rendered in the Authorised Version "devils," and in other versions "goats." Maimonides states that the Sabian astrologers worshipped these *seirim*, which seems to confirm the idea that they were celestial bodies.

2. In *Isaiah* xiv. 12 we find, "How art thou fallen from heaven, O Lucifer, son of the morning! how art thou cut down to the ground, which didst weaken the nations! For thou hast said in thy heart, I will ascend into heaven, I will exalt my throne above

[c] *Prognostication Euerlastinge*, 2nd ed., London, 1576, fol. 6.
[d] Milton, *Paradise Lost*.
[e] *La Grande Comète qui a paru à la Naissance de Napoléon le Grand.*

the stars of God." In this passage a certain Hillel is said to have fallen from heaven; but it is unknown what Hillel means. Some interpreters derive the word from Hebrew verbs signifying to glory, boast, agitate, howl, &c. Hillel *may* therefore signify a comet, for it answers to the ideas of brightness, swift motion, and calamity.

3. In the *General Epistle of St. Jude*, verse 13, certain impious impostors are compared to "wandering stars, to whom is reserved the blackness of darkness for an æon [age]." In all probability the passage may be taken to refer to comets[f].

4. The last quotation which I make is from the *Revelation of St. John the Divine*, xii. 3:—"There appeared another wonder in heaven; and behold a great red dragon, ... and his tail drew the third part of the stars of heaven." Satan is here likened to a comet, because a comet resembles a dragon (or serpent) in form, and its tail frequently does compass or take hold of the stars.

These ideas are given for what they are worth, and that is probably not much.

[f] See Alford's *New Test. for English Readers*. In loco.

CHAPTER VI.

A CATALOGUE OF ALL THE COMETS WHOSE ORBITS HAVE HITHERTO BEEN COMPUTED.

WHEN a new comet has been discovered, the first thing that an astronomer does is to obtain 3 observations of it, whereby he may compute the elements of the orbit. He then examines a catalogue of comets to see if he can identify the newly-found stranger with any that have been before observed. The value of a complete catalogue is obvious; and therefore I have been led to compile a new one.

In the preparation of the following list, care has been taken that only the most reliable orbits that were to be obtained should be inserted, the general rule being to prefer the one which was derived from the longest arc, other things being satisfactory. Among the authorities consulted may be mentioned *Pingré*, *Hussey*, *Olbers*, *Cooper*, *Hind*, *Arago*, *Galle*, and others.

From the publications of the *Royal Astronomical Society of London*, and from the *Astronomische Nachrichten*, much valuable information has also been obtained.

The Epoch of perihelion passage is expressed in Greenwich Mean Time, N.S., since 1582.

The periods assigned in the column of "Duration of Visibility" are subject to much uncertainty, more especially in the case of the ancient comets.

No.	No.	Year.	PP.	π	☊	ι	q
			d. h.	° °	° °	°	
1	1	370 B.C.	Winter	150—210	270—330	above 30	very sm.
2	2	136	April 29	230	220	20	1·01
3	3	68	July	300—330	150—180	70	0·80
4	4	11	Oct. 8 19	280	28	10±	0·58
				° ′	° ′	° ′	
5	(4)	66 A.D.	Jan. 14 4	325 0	32 40	40 30	0·445
6	(4)	141	March 29 2	251 55	12 50	17 0	0·720
7	5	178	Sept. beg.	290	190	18	0·5
8	(4)	218	April 6	....	....	....	....
9	6	240	Nov. 9 23	271 0	189 0	44 0	0·372
10	(4)	295	April 1±	....	....	....	....
11	(4)	451	July 3 12	....	....	....	....
12	7	539	Oct. 20 14	313 30	58 or 238	10	0·341
13	8	565 ii.	July 11 18	84	158 45	60 30	0·775
14	9	568 ii.	Aug. 29 7	318 35	294 15	4 8	0·907
15	10	574	April 7 6	143 39	128 17	46 31	0·963
16	(4)	760	June 11	....	....	....	....
17	11	770	June 6 14	357 7	90 59	61 49	0·642
18	12	837 i.	Feb. 28 23	289 3	206 33	10—12	0·580
19	13	961	Dec. 30 3	268 3	350 35	79 33	0·552
20	(4)	989 ii.	Sept. 11 23	264	84	17	0·568
21	14	1006	March 22	304	38	17 30	0·583
22	(4)	1066	April 1 0	264 55	25 50	17 0	0·720
23	15	1092	Feb. 15 0	156 20	125 40	28 55	0·928
24	16	1097 i.	Sept. 21 21	332 30	207 30	73 30	0·738
25	17	1231	Jan. 30 7	134 48	13 30	6 5	0·948

1. It is said to have separated into two parts.
3. It had a short but brilliant tail.
4. An apparition of *Halley's comet* (?), mentioned by Dion Cassius as having been suspended over Rome previous to the death of Agrippa.
5. An apparition of *Halley's comet* (?). It had a tail 8° long.
6. An apparition of *Halley's comet.*
9. Elements somewhat doubtful. It had a tail 30° long.
11. Undoubtedly an apparition of *Halley's comet.*
12. It had a tail 10 feet long ! !
13. A mean orbit. It had a tail 10° long.
14. Elements very reliable. On Sept. 8 it had a tail 40° long.
15. Elements very uncertain.

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	–	Pingré	....	Greek obs.	(?)
1·0	–	Peirce	....	Chinese obs.	5 weeks.
1·0	+	Peirce	68, July 23	Chinese obs.	5 weeks.
1·0	–	Hind	11, Aug. 26	Chinese obs.	9 weeks.
1·0	–	Hind	66, Jan. 31	Chinese obs.	7 weeks.
1·0	–	Hind	141, Mar. 27	Chinese obs.	4 weeks.
1·0	+	Hind			
1·0	..	Hind	218, April	....	6 weeks.
1·0	+	Burckhardt	240, Nov. 10	Chinese obs.	6 weeks.
..	..	Hind	295	....	7 weeks.
1·0	..	Laugier	451, May 17	Chinese obs.	13 weeks.
1·0	+	Burckhardt	539, Nov. 17	Chinese obs.	9 weeks.
1·0	–	Burckhardt	565, Aug. 4	Chinese obs.	15 weeks.
1·0	+	Laugier	568, Sept. 3	Chinese obs.	10 weeks.
1·0	+	Hind	574, May 2	Chinese obs.	13 weeks (?).
1·0	..	Laugier	760, May 16	Chinese obs.	8 weeks.
1·0	–	Laugier	770, May 26	Chinese obs.	10 weeks.
1·0	–	Pingré	837, Mar. 22	Chinese obs.	5 weeks.
1·0	–	Hind	962, Jan. 28	Chinese obs.	5 weeks.
1·0	–	Burckhardt	989, July 28	Chinese obs.	5 weeks.
1·0	–	Pingré	1006, April	European obs.	3 or 6 weeks.
1·0	–	Hind	1066, April 2	Chinese obs.	6 weeks or +.
1·0	+	Hind	1092, Jan. 8	Chinese obs.	17 weeks.
1·0	+	Burckhardt	1097, Sept. 30	Chinese obs.	4 weeks.
1·0	+	Pingré	1231, Feb. 6	Chinese obs.	4 weeks.

16. An apparition of *Halley's comet.*
17. It had a tail about 30° long.
18. Tolerably trustworthy. The maximum length of the tail was 80°, but it dwindled down to 30° in a fortnight.
20. Probably an apparition of *Halley's comet.* Mentioned by several Saxon writers.
21. These elements appear to have escaped the notice of recent cometographers, though given by Pingré; but has it been confounded with the following?
22. Possibly an apparition of *Halley's comet.* This is the famous object which created such universal dread throughout Europe in 1066. In England it was looked upon as a presage of the success of the Norman invasion.
23. Elements satisfactory.
24. A tail 50° long was seen in China, and much bifurcated.

No.	No.	Year.	PP.	π	☊	ι	q
			d. h.	° ′	° ′	° ′	
26	18	1264	July 15 23	272 30	175 30	30 25	0·430
27	19	1299	March 31 7	3 20	107 8	68 57	0·318
28	(4)	1301 i.	Oct. 23 23	312	138	13	0·640
29	20	1337 i.	June 15 1	2 20	93 1	40 28	0·828
30	21	1351	Nov. 25 23	69	Indeterminate.		1·0
31	22	1362 i.	March 11 4	219	249	21	0·456
32	23	1366	Oct. 13	66	212	6	0·958
33	(4)	1378	Nov. 8 18	299 31	47 17	17 56	0·583
34	24	1385	Oct. 16 6	101 47	268 31	52 15	0·774
[redacted]	25	1433	Nov. 5 4	262 1	110 9	77 14	0·329
36	26	1449	Dec. 9	60	143	75 30	0·15
37	(4)	1456	June 8 22	301	48 30	17 56	0·586
38	27	1457 iii.	Sept. 3 16	92 50	256 5	20 20	2·103
39	28	1462	Aug. 6 3	196	25	18	0·31
40	29	1468 ii.	Oct. 7 6	356 3	61 15	44 19	0·855
41	30	1472	Feb. 28 5	48 3	207 32	1 55	0·539
42	31	1490 {	Dec. 24 11	58 40	288 45	51 37	0·738
			Dec. 25 21	113	268	75	0·755
43	32	1499	Sept. 6 18	0	326 30	21	0·954
44	33	1500	May 17	290	310	75	1·4
45	34	1506	Sept. 3 15	250 37	132 50	45 1	0·386
46	(4)	1531	Aug. 24 21	301 39	49 25	17 56	0·5670
47	35	1532 {	Oct. 19 14	135 44	119 8	42 27	0·6125
			Oct. 19 22	111 7	80 27	32 36	0·5091
48	36	1533 {	June 14 21	217 40	299 19	28 14	0·3269
			June 16 19	104 12	125 44	35 49	0·2028

26. One of the grandest comets on record. Its tail is said to have been 100° long. Hoek has published several orbits all differing much from Pingré's.

27. Elements very doubtful.

28. Probably an apparition of *Halley's comet.*

29. A fine comet. The elements assigned by Halley, Pingré, and Hind differ somewhat from those here given.

30. Very uncertain. No latitudes given.

31. Uncertain. The tail was 20 *feet long*, and the head was *the size of a wine-glass!*

32. Very uncertain.

33. An apparition of *Halley's comet.*

34. Tolerably certain. The tail was 10° long.

37. An apparition of *Halley's comet.* It had a splendid tail, 60° long. At one time the head was round, and the size of a bull's eye, and the tail like that of a peacock!! (*Chinese Obs.*)

38. Only approximate. It had a tail 15° long.

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Pingré	1264, July 14	Chinese & European	3 months.
1·0	—	Pingré	1299, Jan. 24	Chinese obs.	11 weeks.
1·0	—	Laugier	1301, Sept. 16	Chinese & European	6 weeks.
1·0	—	Laugier	1337, May	Chinese & European	3 or 4 months.
1·0	+	Burckhardt	1351, Nov. 24	Chinese obs.	1 week.
1·0	—	Burckhardt	1362, Mar. 5	Chinese obs.	5 weeks.
1·0	..	Peirce	1366, Aug. 26	Chinese obs.	Several days.
1·0	—	Laugier	1378, Sept. 26	Chinese obs.	6 weeks.
1·0	—	Hind	1385, Oct. 23	Chinese obs.	(?)
1·0	—	Hind	1433, Oct. 12	Chinese obs.	2 months.
1·0	+	Hind	1450, Jan. 19	Chinese obs.	(?)
1·0	—	Pingré	1456, May 29	European & Chinese	1 month.
1·0	+	Hind	1457, June	European obs.	3 months.
1·0	—	Hind	1462	Chinese obs.	
1·0	—	Laugier	1468, Sept.	European obs.	2 or 3 months.
1·0	—	Laugier	1471, Dec.	Regiomontanus	3 months.
1·0	+	Hind }	1491, Jan.	Chinese obs.	(?)
1·0	—	Peirce }			
1·0	+	Hind	1499	Chinese obs.	(?)
1·0	—	Hind	1500, April	European & Chinese	3 weeks or +.
1·0	—	Laugier	1506, July 31	Chinese obs.	2 weeks.
1·0	—	Halley	1531, Aug. 1 ±	P. Apian	5 weeks.
1·0	+	Méchain }	1532, Sept. 22	P. Apian	16 weeks.
1·0	+	Halley }			
1·0	+	Olbers }	1533, June	P. Apian	2½ months.
1·0	—	Douwes }			

40. Uncertain. It had a tail 30° long.

41. A celebrated comet. When at its least distance from the Earth (3,300,000 miles), on Jan. 21, it was quite visible in full daylight. It had a fine tail, which the Chinese say was *as long as a street!*

42. Uncertain.

43. In the middle of August this Comet seems to have approached very near to the Earth.—(Hind, MSS. *communicated.*)

44. Elements uncertain. It was *as large as a ball!* and had a tail from 3° to 5° long.

46. An apparition of *Halley's comet.* It had a tail 7° long.

47. It had a tail several degrees long. Olbers has computed an orbit which agrees well with Halley's, but Méchain's is considered the best.

48. According to Olbers, both these orbits will satisfy the observations, and it is as yet impossible to decide between them. It had a tail 15° long.

No.	No.	Year.	PP.	π	☊	ι	q
			d. h.	° ′	° ′	° ′	
49	(18)	1556	April 22 0	274 14	175 25	30 12	0·5049
50	37	1558	Aug. 10 12	329 49	332 36	73 29	0·5773
51	38	1577	Oct. 26 22	129 42	25 20	75 9	0·1775
52	39	1580	Nov. 28 12	108 26	19 6	64 33	0·6023
53	40	1582	May 6 16	245 23	231 7	61 27	0·2257
			May 6 10	256 15	229 18	60 47	0·1683
54	41	1585	Oct. 8 0	9 8	37 44	6 5	1·0948
55	42	1590	Feb. 8 0	217 57	165 37	29 29	0·5677
56	43	1593	July 18 13	176 19	164 15	87 58	0·0891
57	44	1596	July 25 5	270 54	330 20	51 58	0·5671
58	(4)	1607	Oct. 27 0	300 46	48 14	17 6	0·5841
59	45	1618 i.	Aug. 17 3	318 20	293 25	21 28	0·5129
60	46	— iii.	Nov. 8 8	3 5	75 44	37 11	0·3895
61	47	1652	Nov. 12 15	28 18	88 10	79 28	0·8475
62	(35 ?)	1661	Jan. 26 21	115 16	81 54	33 0	0·4427
63	48	1664	Dec. 4 12	130 33	81 15	21 18	1·0255
64	49	1665	April 24 5	71 54	228 2	76 5	0·1064
65	50	1668	Feb. 24 18	40 9	193 26	27 7	0·2511
			Feb. 28 19	277 2	357 17	35 58	0·0047
66	51	1672	March 1 8	46 59	297 30	83 22	0·6974
67	52	1677	May 6 0	137 37	236 49	79 3	0·2805
68	53	1678	Aug. 18 7	322 47	163 20	2 52	1·1453

49. A very fine comet, which was expected to return in 1860.

51. It had a tail 22° long. This comet formed the subject of the observations of Tycho Brahe for the detection of parallax.

52. Elements approximate. Observed also by Tycho Brahe.

53. Very uncertain. It had a faint tail 3° long, which resembled a piece of silk !!

54. This orbit was computed some years ago, to see whether the comet of 1844 (ii) was identical with this one.

55. It had a tail 7° long.

56. It had a tail 4½° long.

57. Discovered also by Tycho Brahe.

58. An apparition of *Halley's comet.* It had a tail 7° long.

59. Somewhat uncertain. Seen at Lintz, Aug. 27, and by Kepler, Sept. 1.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Hind	1556, Feb. 28	P. Fabricius	10 weeks.
1·0	—	Olbers	1558, July 14	Landgrave of Hesse	6 weeks.
1·0	—	Woldstedt	1577, Nov. 1	In Peru	12 weeks.
1·0	+	Schjellerup	1580, Oct. 2	Mœstlin	10 weeks.
1·0	—	Pingré	1582, May 12	Tycho Brahe	3 weeks.
1·0	—	D'Arrest			
1·0	+	C. A. Peters and Sawitsch	1585, Oct. 19	Tycho Brahe & Rothmann	4 weeks.
1·0	—	Hind	1590, Mar. 5	Tycho Brahe	3 weeks.
1·0	+	La Caille	1593, July 20	De Rissen	6 weeks.
1·0	—	Hind	1596, July 11	Mœstlin	5 weeks.
0·96708	—	Lehmann	1607, Sept. 11	Kepler	9 weeks.
1·0	+	Pingré	1618, Aug. 25	At Caschau	4 weeks.
1·0	+	Bessel	— Nov. 30	Many observers.	7 weeks.
1·0	+	Halley	1652, Dec. 20	Hevelius	3 weeks.
1·0	+	Méchain	1661, Feb. 3	Hevelius	5 weeks.
1·0	—	Lindelof	1664, Nov. 17	In Spain	17 weeks.
1·0	—	Halley	1665, Mar. 27	At Aix	4 weeks.
1·0	+	Henderson	1668, Mar. 5	Gottignies, etc.	3 weeks.
1·0	—	Henderson			
1·0	+	Halley	1672, Mar. 2	Hevelius	7 weeks.
1·0	—	Halley	1677, April 27	Hevelius	12 days.
0·62697	+	Le Verrier	1678, Sept. 11	La Hire	4 weeks.

60. A splendid comet; it had a tail, according to Longomontanus, 104° long, and of a reddish hue. Said to have been visible in the daytime.

61. Elements only approximate.

62. By some supposed to be identical with the comet of 1532; it was not re-observed, however, as was anticipated, about 1791.

63. It had a tail from 6° to 10° long.

64. It had a tail 25° long.

65. Seen chiefly in the southern hemisphere; both orbits satisfy the observations, and it is impossible to say which is the correct one.

66. It had a tail about 1° long.

67. It had a tail about 6° long.

68. Elements only approximate.

No.	No.	Year.	PP.	ϖ	☊	ι	q
			d. h.	° ′	° ′	° ′	
69	54	1680	Dec. 17 23	262 49	272 9	60 40	0·0062
70	(4)	1682	Sept. 14 19	301 55	51 11	17 44	0·5829
71	55	1683	July 13 2	85 35	173 24	83 13	0·5595
72	56	1684	June 8 10	238 52	268 15	65 48	0·9601
73	57	1686	Sept. 16 14	77 0	350 34	31 21	0·3250
74	58	1689	Nov. 29 4	269 41	90 25	59 4	0·0189
75	59	1695	Nov. 9 16	60	216	22	0·8435
76	60	1698	Oct. 18 16	270 51	267 44	11 46	0·6912
77	61	1699 i.	Jan. 13 8	212 31	321 45	69 20	0·7440
78	62	1701	Oct. 17 9	133 41	298 41	41 39	0·5926
79	63	1702 ii.	March 13 14	138 46	188 59	4 24	0·6468
80	64	1706	Jan. 30 4	72 29	13 11	55 14	0·4258
81	65	1707	Dec. 11 23	79 54	52 46	88 36	0·8597
82	66	1718	Jan. 14 21	121 39	127 55	31 8	1·0254
83	67	1723	Sept. 27 15	42 52	14 14	50 0	0·9987
84	68	1729	June 13 6	320 31	310 38	77 5	4·0435
85	69	1737 i.	Jan. 30 8	325 55	226 22	18 20	0·2228
86	70	— ii.	June 8 7	262 36	123 53	39 14	0·8670
87	71	1739	June 17 10	102 38	207 25	55 42	0·6735
88	72	1742 i.	Feb. 8 4	217 35	185 38	66 59	0·7656
89	73	1743 i.	Jan. 8 4	93 19	86 54	1 53	0·8615
90	74	— ii.	Sept. 20 21	247 0	6 2	45 37	0·5229
91	75	1744	March 1 8	197 12	45 45	47 8	0·2220

69. A splendid comet, whose tail ultimately attained a length of from 70° to 90°. Halley conjectured that this was a return of the comet of 1106, 531 A.D., and 42 B.C., but this has since been shewn to be unlikely. The orbit here given supposes a period of 8814 years; this, however, is subject to much uncertainty, inasmuch as the observations might possibly be satisfied by an 805 years' ellipse, or even by a hyperbolic orbit.

70. An apparition of *Halley's comet*. It had a tail from 12° to 16° long.

71. It had a tail varying from 2° to 4°.

73. Its nucleus was as bright as a 1st-magnitude star, and it had a tail 18° long.

74. Observed very roughly in the East Indies. It had a tail 60° long. Pingré makes the ☊ = 323° 45′.

75. Observed still more imperfectly than the last in the southern hemisphere. It had a tail 18° long.

76. Uncertain.

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·99998	+	Encke	1680, Nov. 14	At Coburg	18 weeks.
0·96792	—	Rosenberger	1682, Aug. 15	Flamsteed	5 weeks.
1·0	—	Plummer	1683, July 23	Flamsteed	6 weeks.
1·0	+	Halley	1684, July 1	Bianchini	2 weeks.
1·0	+	Halley	1686, Aug.	In India	1 month.
1·0	—	Vogel	1689, Dec. 10	Richaud	2 weeks.
1·0	+	Burckhardt	1695, Oct. 28	Jacob	3 weeks.
1·0	—	Halley	1698, Sept. 2	La Hire	4 weeks.
1·0	—	La Caille	1699, Feb. 17	Fontenay	2 weeks.
1·0	—	Burckhardt	1701, Oct. 28	Pallu	1 week.
1·0	+	Burckhardt	1702, April 20	Bianchini	2 weeks.
1·0	+	La Caille	1706, Mar. 18	J. D. Cassini	4 weeks.
1·0	+	La Caille	1707, Nov. 25	Manfredi	8 weeks.
1·0	—	Argelander	1718, Jan. 18	Kirch	3 weeks.
1·0	—	Spörer	1723, Oct. 12	At Bombay	9 weeks.
1·00503	+	Burckhardt	1729, July 31	Sarabat	25 weeks.
1·0	+	Bradley	1737, Feb. 6	In Jamaica	4 weeks.
1·0	+	Daussy	— Feb.	At Pekin	(?)
1·0	—	La Caille	1739, May 28	Zanotti	11 weeks.
1·0	—	La Caille	1742, Feb. 5	Cape of G. Hope	13 weeks.
0·72130	+	Clausen	1743, Feb. 10	Grischau	2 weeks.
1·0	—	D'Arrest	— Aug. 18	Klinkenberg	4 weeks.
1·0	+	Betts	— Dec. 9	Klinkenberg	4 months (?)

78. Observed also by Thomas at Pekin.
79. Very roughly observed; visible to the naked eye.
81. Discovered by J. D. Cassini, Nov. 29.
83. Afterwards seen in Europe, with a faint tail 1° long.
84. Scarcely perceptible to the naked eye. The orbit is a hyperbolic one, and remarkable for its enormous perihelion distance, the greatest known.
86. Elements only approximate.
88. Visible to the naked eye, with a tail 6° or 8° long.
89. Very imperfectly observed. An elliptic orbit; period assigned, 5·436 years.
90. Very uncertain. Visible to the naked eye.
91. The finest comet of the 18th century. On Feb. 15 it had a bifid tail, the eastern portion being 7° long, and the western 24°. Visible in a telescope in the daytime. Euler has calculated an elliptic orbit, to which he assigns a period of 122,683 years!! The statement of this comet having had six tails (at one time disbelieved) has been confirmed by the testimony of De Lisle discovered by Winnecke.

No.	No.	Year.	PP.	ϖ	☊	ι	q
			d. h.	° ′	° ′	° ′	
92	(17?)	1746	Feb. 15 0	140 0	335 0	6 0	0·95
93	76	1747	March 3 7	277 2	147 18	79 6	2·1985
94	77	1748 i.	April 28 18	215 23	232 51	85 28	0·8404
95	78	— ii.	June 18 21	278 47	33 8	67 3	0·6253
96	79	1757	Oct. 21 7	122 58	214 12	12 50	0·3375
97	80	1758	June 11 3	267 38	230 50	68 19	0·2153
98	(4)	1759 i.	March 12 13	303 10	53 50	17 36	0·5845
99	81	— ii.	Nov. 27 2	53 24	139 39	78 59	0·7985
100	82	— iii.	Dec. 16 21	138 24	79 50	4 51	0·9659
101	83	1762	May 28 8	104 2	348 33	85 38	1·0090
102	84	1763	Nov. 1 20	84 58	356 24	72 31	0·4982
103	85	1764	Feb. 12 13	15 14	120 4	52 53	0·5552
104	86	1766 i.	Feb. 17 8	143 15	244 10	40 50	0·5053
105	87	— ii.	April 26 23	251 13	74 11	8 1	0·3989
106	88	1769	Oct. 7 14	144 11	175 3	40 45	0·1227
107	89	1770 i.	Aug. 13 12	356 16	131 59	1 34	0·6743
108	90	— ii.	Nov. 22 5	208 22	108 42	31 25	0·5282
109	91	1771	April 19 5	104 3	27 51	11 15	0·9034
110	92	1772	Feb. 19 2	110 14	254 0	18 17	1·0136
111	93	1773	Sept. 5 14	75 10	121 5	61 14	1·1268
112	94	1774	Aug. 15 19	317 27	180 44	83 20	1·4328
113	95	1779	Jan. 4 2	87 14	25 4	32 30	0·7131
114	96	1780 i.	Sept. 30 22	246 35	123 41	54 23	0·0963

92. Elements uncertain, but they strongly resemble those of the comet of 1231. It passed very near the Earth.

93. Observed only during 1746.

94. Discovered by J. D. Maraldi, April 30. Visible to the naked eye, with a tail 2° long.

95. Very uncertain.

96. Elements tolerably reliable. It had a small tail.

98. The first *predicted* apparition of *Halley's comet.* On May 5 its tail was 47° long.

99. Visible to the naked eye, with a tail 5° long. Elements resemble those of the comet of 1449.

100. This comet came near the Earth, and moved with great rapidity; it had a tail 4° long.

101. It had a small tail.

102. An elliptic orbit; period assigned, 7334 years. Lexell makes it 1137 years.

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Hind	1746, Feb. 2	Kindermans	4 weeks.
1·0	−	La Caille	— Aug. 13	Chésaux	15 weeks.
1·0	−	Le Monnier	1748, April 26	At Pekin	9 weeks.
1·0	+	Bessel	— May 19	Klinkenberg	4 days.
1·0	+	Bradley	1757, Sept. 13	Bradley	5 weeks.
1·0	+	Pingré	1758, May 26	La Nux	5 months.
0·96768	−	Rosenberger	— Dec. 25	Palitzch	5 months.
1·0	+	La Caille	1760, Jan. 25	Messier	8 weeks.
1·0	−	La Caille	— Jan. 7	At Lisbon	14 weeks.
1·0	+	Burckhardt	1762, May 17	Klinkenberg	6 weeks.
0·99868	+	Burckhardt	1763, Sept. 28	Messier	8 weeks.
1·0	−	Pingré	1764, Jan. 3	Messier	6 weeks.
1·0	−	Pingré	1766, March 8	Messier	9 weeks.
0·8640	+	Burckhardt	— April 1	Helfenzrieda	6 weeks.
0·99924	+	Bessel	1769, Aug. 8	Messier	16 weeks.
0·78683	+	Le Verrier	1770, June 14	Messier	15 weeks.
1·0	−	Pingré	1771, Jan. 10	La Nux	8 days.
1·00936	+	Encke	— April 1	Messier	15 weeks.
0·90314	+	Bessel	1772, Mar. 8	Montaigne	3 weeks.
1·0	+	Burckhardt	1773, Oct. 12	Messier	27 weeks.
1·02829	+	Burckhardt	1774, Aug. 11	Montaigne	11 weeks.
1·0	+	Zach	1779, Jan. 6	Bode	19 weeks.
0·99994	−	Clüver	1780, Oct. 26	Messier	5 weeks.

103. Visible to the naked eye, with a tail $2\frac{1}{2}°$ long.

105. Discovered by Messier, April 8. An elliptic orbit; period assigned, 5·025 years. Visible to the naked eye, with a tail 3° or 4° long.

106. Visible to the naked eye, with a tail from 60° to 80° long. Bessel assigns 2090 years as the most likely period of revolution. He has shewn that an error of 5″ either may increase the period to 2673 years or diminish it to 1692 years.

107. The celebrated *Lexell's comet.* The diameter of the head, July 1, was $2\frac{1}{2}°$. It had also a small tail, and approached within 1,400,000 miles of the Earth.

108. It had a faint tail, 5° long.

109. The orbit of this comet is undoubtedly hyperbolic. It had a tail about 2° long.

110. The first recorded apparition of *Biela's comet.*

111. Just perceptible to the naked eye.

113. Discovered by Messier, Jan. 18.

114. An elliptic orbit; period assigned, 75,314 years.

No.	No.	Year.	PP.		π	☊	ι	q
				d. h.	° ′	° ′	° ′	
115	97	1780 ii.	Nov.	28 20	246 52	141 1	72 3	0·5152
116	98	1781 i.	July	7 4	239 11	83 0	81 43	0·7758
117	99	— ii.	Nov.	29 12	16 3	77 22	27 13	0·9610
118	100	1783 i.	Nov.	19 13	49 31	55 12	47 43	1·4953
119	101	1784 i.	Jan.	21 4	80 44	56 49	51 9	0·7078
120	102	— ii.	March	10 0	137	35	84	0·637
121	103	1785 i.	Jan.	27 7	109 51	264 12	70 14	1·1434
122	104	— ii.	April	8 8	297 29	64 33	87 31	0·4273
123	105	1786 i.	Jan.	30 20	156 38	334 8	13 36	0·3348
124	106	— ii.	July	7 21	159 25	194 22	50 54	0·4101
125	107	1787	May	10 19	7 44	106 51	48 15	0·3489
126	108	1788 i.	Nov.	10 7	99 8	156 56	12 27	1·0630
127	109	— ii.	Nov.	20 7	22 49	352 24	64 30	0·7573
128	110	1790 i.	Jan.	15 5	60 14	176 11	31 54	0·7581
129	111	— ii.	Jan.	28 7	111 44	267 8	56 58	1·0632
130	112	— iii.	May	21 5	273 43	33 11	63 52	0·7979
131	113	1792 i.	Jan.	13 13	36 29	190 46	39 46	1·2930
132	114	— ii.	Dec.	27 6	135 59	283 15	49 1	0·9662
133	115	1793 i.	Nov.	4 20	228 42	108 29	60 21	0·4034
134	116	— ii.	Nov.	20 5	71 54	2 0	51 31	1·4951
135	(105)	1795	Dec.	21 10	156 41	334 39	13 42	0·3344
136	117	1796	April	2 19	192 44	17 2	64 54	1·5781
137	118	1797	July	9 2	49 27	329 15	50 40	0·5266
138	119	1798 i.	April	4 11	104 59	122 9	43 52	0·4847
139	120	— ii.	Dec.	31 13	34 27	249 30	42 26	0·7795

115. Discovered by Olbers on the same day.
116. Visible to the naked eye, Nov. 9, with a tail 3° long. It came very near the Earth.
118. An elliptic orbit; period assigned, 5·613 years.
119. Visible to the naked eye, with a tail 2° long.
120. Not only are the elements uncertain, but it is doubtful whether the comet ever existed.
122. Visible to the naked eye, with a tail 8° long.
123. The first recorded apparition of *Encke's comet.*
126. Visible to the naked eye, with a tail 2½° long.
128. Imperfectly observed on four occasions. Elements only approximate.

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	−	Olbers	1780, Oct. 18	Montaigne	3 days.
1·0	+	Méchain	1781, June 28	Méchain	3 weeks.
1·0	−	Méchain	— Oct. 9	Méchain	11 weeks.
0·6784	+	Burckhardt	1783, Nov. 19	Pigott	4 weeks.
1·0	−	Méchain	— Dec. 15	La Nux	23 weeks.
1·0	+	Burckhardt	1784, April 10	D'Angos	5 days.
1·0	+	Méchain	1785, Jan. 7	Messier	5 weeks.
1·0	−	Méchain	— Mar. 11	Méchain	5 weeks.
0·84836	+	Encke	1786, Jan. 17	Méchain	3 days.
1·0	+	Méchain	— Aug. 1	Miss Herschel	12 weeks.
1·0	−	Saron	1787, April 10	Méchain	7 weeks.
1·0	−	Méchain	1788, Nov. 25	Messier	5 weeks.
1·0	+	Méchain	— Dec. 21	Miss Herschel	4 weeks.
1·0	−	Saron	1790, Jan. 7	Miss Herschel	2 weeks.
1·0	+	Méchain	— Jan. 9	Méchain	3 weeks.
1·0	−	Méchain	— April 18	Miss Herschel	10 weeks.
1·0	−	Méchain	1791, Dec. 15	Miss Herschel	6 weeks.
1·0	−	Prosperin	1793, Jan. 8	Gregory	6 weeks.
1·0	−	Saron	— Sept. 27	Messier	15 weeks.
0·97342	+	D'Arrest	— Sept. 24	Perny	10 weeks.
0·84888	+	Encke	1795, Nov. 7	Miss Herschel	3 weeks.
1·0	−	Olbers	1796, Mar. 31	Olbers	2 weeks.
1·0	−	Olbers	1797, Aug. 14	Bouvard	3 weeks.
1·0	+	Burckhardt	1798, April 12	Messier	6 weeks.
1·0	−	Burckhardt	— Dec. 6	Bouvard	1 week.

130. Visible to the naked eye, with a tail 4° long.
132. Discovered by Méchain and Piazzi, Jan. 10. There was a trace of a tail to be seen.
134. Discovered by Miss Herschel, Oct. 7. An elliptic orbit; period assigned, 422 years.
135. An apparition of *Encke's comet.* It was just visible to the naked eye.
136. Very faint.
137. Discovered by Miss Herschel and Lee on the same evening; by Rüdiger, Aug. 15, and by Kecht, Aug. 16.
139. Discovered by Olbers, Dec. 18. Elements only approximate.

No.	No.	Year.	PP.		ϖ	☊	ι	q
				d. h.	° ′	° ′	° ′	
140	121	1799 i.	Sept.	7 5	3 39	99 32	50 56	0·8399
141	(61)	— ii.	Dec.	25 21	190 20	326 49	77 1	0·6258
142	122	1801	Aug.	8 13	182 41	42 28	20 45	0·2564
143	123	1802	Sept.	9 21	332 9	310 15	57 0	1·0941
144	124	1804	Feb.	13 15	148 53	176 49	56 44	1·0772
145	(105)	1805	Nov.	21 12	156 47	334 20	13 33	0·3404
146	(92)	1806 i.	Jan.	1 23	109 32	251 15	13 38	0·9068
147	125	— ii.	Dec.	28 22	97 2	322 19	35 2	1·0815
148	126	1807	Sept.	18 17	270 54	266 47	63 10	0·6461
149	127	1808 ii.	May	12 22	69 12	322 58	45 43	0·3898
150	128	— iii.	July	12 4	252 38	24 11	39 18	0·6079
151	129	1810	Oct.	5 19	63 9	308 53	62 46	0·9691
152	130	1811 i.	Sept.	12 6	75 0	140 24	73 2	1·0354
153	131	— ii.	Nov.	10 23	47 27	93 1	31 17	1·5821
154	132	1812	Sept.	15 7	92 18	253 1	73 57	0·7771
155	133	1813 i.	March	4 12	69 56	60 48	21 13	0·6991
156	134	— ii.	May	19 10	197 43	42 40	81 2	1·2161
157	135	1815	April	25 23	149 2	83 28	44 29	1·2128
158	136	1816	March	1 8	267 35	323 14	43 5	0·0485
159	137	1818 i.	Feb.	3 5	76 18	256 1	34 11	0·6959
160	138	— ii.	Feb.	25 23	182 45	70 26	89 43	1·1977
161	139	— iii.	Dec.	4 22	101 55	89 59	63 5	0·8550
162	(105)	1819 i.	Jan.	27 6	156 59	334 33	13 36	0·3352

140. Discovered by Olbers, Aug. 26. At first faint, but afterwards visible to the naked eye, with a tail 10° long.

141. Probably a return of the comet of 1699. Visible to the naked eye, with a tail from 1° to 3° long.

142. Discovered at Paris, July 12. Elements resemble those of the comet of 1462.

143. Discovered by Méchain, Aug. 28, and by Olbers, Sept. 2.

144. Discovered by Bouvard, March 10, and by Olbers, March 12.

145. An apparition of *Encke's comet*. Discovered by Pons, Huth, and Bouvard, Oct. 20. Visible to the naked eye, with a tail 3° long.

146. An apparition of *Biela's comet*. Discovered by Bouvard, Nov. 16, and by Huth, Nov. 22. Visible to the naked eye.

148. Discovered by Pons, Sept. 20. It was visible to the naked eye, with a tail 5° long. An elliptic orbit; period assigned, 1714 years, which may, however, be extended to 2157 years or reduced to 1403 years.

149. Discovered by Wisniewski, March 29.

150. Elements only approximate.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	—	Burckhardt	1779, Aug. 7	Méchain	3 weeks.
1·0	—	Méchain	— Dec. 26	Méchain	10 days.
1·0	—	Doberck	1801, June 30	Reissig	3 weeks.
1·0	+	Olbers	1802, Aug. 26	Pons	6 weeks.
1·0	+	Bouvard	1804, Mar. 7	Pons	3 weeks.
0·84617	+	Encke	1805, Oct. 19	Thulis	3 weeks.
0·74578	+	Gambart	— Nov. 10	Pons	4 weeks.
1·0	—	Burckhardt	1806, Nov. 10	Pons	14 weeks.
0·99548	+	Bessel	1807, Sept. 9	Parisi	28 weeks.
1·0	—	Encke	1808, Mar. 25	Pons	1 week.
1·0	—	Bessel	— June 24	Pons	10 days.
1·0	+	Bessel	1810, Aug. 22	Pons	6 weeks.
0·99509	—	Argelander	1811, Mar. 26	Flaugergues	17 months.
0·98271	+	Nicolai	— Nov. 16	Pons	13 weeks.
0·95454	+	Encke	1812, July 20	Pons	10 weeks.
1·0	—	Nicollett	1813, Feb. 4	Pons	5 weeks.
1·0	—	Encke	— Mar. 28	Pons	6 weeks.
0·93121	+	Bessel	1815, Mar. 6	Olbers	25 weeks.
1·0	+	Burckhardt	1816, Jan. 22	Pons	11 days.
1·0	+	Hind	1818, Feb. 23	Pons	4 days.
1·0	+	Encke	1817, Dec. 26	Pons	18 weeks.
1·0	—	Rosenberger	1818, Nov. 28	Pons	9 weeks.
0·84858	+	Encke	— Nov. 26	Pons	7 weeks.

152. A very celebrated comet, conspicuously visible in the evenings of the autumn of 1811. It had a tail 25° long and 6° broad. The most reliable computations assign a periodic term of 3065 years, subject to an uncertainty of not more than 43 years. The orbit of this comet is liable to much planetary perturbation.

153. An elliptic orbit; period assigned, 875 years. Visible to the naked eye.

154. An elliptic orbit; period assigned, 70·68 years. Visible to the naked eye, with a tail 2° long.

156. Discovered also by Harding, April 3. Visible to the naked eye.

157. An elliptic orbit; period assigned, 70·049 years. Bessel anticipates that planetary perturbation will bring it back to perihelion, 1887, Feb. 9. It had a short tail.

158. Elements only approximate.

159. The observations were few and indifferent.

161. Discovered by Bessel, Dec. 22. It moved very rapidly. Rosenberger has computed a hyperbolic orbit.

162. An apparition of *Encke's comet*, the periodicity of which was now discovered.

No.	No.	Year.	PP.			ϖ		☊		ι		q
				d.	h.	°	′	°	′	°	′	
163	140	1819 ii.	June	27	17	287	8	273	42	80	44	0·3410
164	141	— iii.	July	18	21	274	40	113	10	10	42	0·7736
165	142	— iv.	Nov.	20	5	67	18	77	13	9	1	0·8925
166	143	1821	March	21	12	239	29	48	40	73	3	0·0918
167	144	1822 i.	May	5	14	192	43	177	26	53	37	0·5044
168	(105)	— ii.	May	23	23	157	11	334	25	13	20	0·3459
169	145	— iii.	July	16	12	218	32	97	40	38	12	0·8367
170	146	— iv.	Oct.	23	18	271	40	92	44	52	39	1·1450
171	147	1823	Dec.	9	10	274	34	303	3	76	11	0·2265
172	148	1824 i.	July	11	12	260	16	234	19	54	34	0·5912
173	149	— ii.	Sept.	29	1	4	31	279	15	54	36	1·0501
174	(112)	1825 i.	May	30	13	273	55	20	6	56	41	0·8891
175	150	— ii.	Aug.	18	17	10	14	192	56	89	41	0·8834
176	(105)	— iii.	Sept.	16	6	157	14	334	27	13	21	0·3448
177	151	— iv.	Dec.	10	16	318	46	215	43	33	32	1·2408
178	(92)	1826 i.	March	18	9	109	45	251	28	13	33	0·9025
179	152	— ii.	April	21	23	116	54	197	38	40	2	2·0111
180	153	— iii.	April	29	0	35	48	40	29	5	17	0·1881
181	154	— iv.	Oct.	8	22	57	48	44	6	25	57	0·8528
182	155	— v.	Nov.	18	9	315	31	235	7	89	22	0·0268
183	156	1827 i.	Feb.	4	22	33	30	184	27	77	35	0·5065
184	157	— ii.	June	7	20	297	31	318	10	43	38	0·8081

163. A very brilliant comet, with a tail 7° long.

164. An elliptic orbit; period assigned, 5·618 years. Considered by Clausen as a return of the comet of 1766 (ii).

165. Discovered by Pons, Dec. 4. An elliptic orbit; period assigned, 4·810 years. Clausen thought this comet might be identical with that of 1743 (i).

166. Discovered by Nicollet on the same day, and by Blainpain, Jan. 25. Visible to the naked eye, with a tail 2½° long.

167. Discovered by Pons, May 14, and by Biela, May 17.

168. The first predicted apparition of *Encke's comet.* Seen only in New South Wales.

169. Its apparent motion was very rapid.

170. Discovered by Gambart, July 16. An elliptic orbit; period assigned, 5444 years. Visible to the naked eye, with a tail 1½° long.

171. Discovered by Pons, Dec. 29; by Kohler, Dec. 30; and by Santini, Jan. 3. This comet had, in addition to the usual tail turned from the Sun, another turned *towards it.*

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Bouvard	1819, July 1	Tralles	16 weeks.
0·75519	+	Encke	— June 12	Pons	5 weeks.
0·68674	+	Encke	— Nov. 28	Blainpain	8 weeks.
1·0		Rosenberger	1821, Jan. 21	Pons	15 weeks.
1·0	−	Nicollet	1822, May 12	Gambart	7 weeks.
0·84446	+	Encke	— June 2	Rümker	3 weeks.
1·0	−	Heiligenstein	— May 31	Pons	2 weeks.
0·99630	−	Encke	— July 13	Pons	17 weeks.
1·0	−	Encke	1823, Dec. 1	In Switzerland	13 weeks.
1·0	−	Rümker	1824, July 15	Rümker	4 weeks.
1·00173	+	Encke	— July 23	Scheithauer	22 weeks.
1·0	−	Clausen	1825, May 19	Gambart	8 weeks.
1·0	+	Clausen	— Aug. 9	Pons	3 weeks.
0·84488	+	Encke	— July 13	Valz	8 weeks.
0·99536	−	Hansen	— July 15	Pons	12 months.
0·74657	+	Santini	1826, Feb. 27	Biela	8 weeks.
1·0	+	Clausen	1825, Nov. 6	Pons	22 weeks.
1·0	−	Clüver	1826, Mar. 29	Flaugergues	9 days.
1·0	+	Argelander	— Aug. 7	Pons	15 weeks.
1·0	−	Clüver	— Oct. 22	Pons	11 weeks.
1·0	−	Heiligenstein	— Dec. 26	Pons	5 weeks.
1·0	−	Heiligenstein	1827, June 20	Pons	4 weeks.

172. Seen only in the southern hemisphere.

173. Discovered by Pons, July 24, and afterwards by Gambart and Harding.

174. It had a tail $1\frac{1}{2}°$ long. Elements resemble those of 1790 (iii).

175. Discovered by Harding, Aug. 23. Orbit remarkable for its great inclination.

176. An apparition of *Encke's comet.* Discovered by Plana, Aug. 10, and by Pons, Aug. 14.

177. Discovered by Biela, July 19. Very conspicuous early in October, with a bifid tail 15° long. An elliptic orbit; period assigned, 4386 years.

178. An apparition of *Biela's comet*, whose periodicity was now discovered. Found by Gambart, March 9.

180. Elements uncertain.

181. The path of this comet crosses the ecliptic near the Earth's orbit.

182. Discovered by Clausen, Oct. 26, and by Gambart, Oct. 28. Visible to the naked eye, with a tail $\frac{1}{4}°$ long.

184. Discovered also by Gambart. Elements resemble those of the comet of 1500.

No.	No.	Year.	PP.			π	☊	ι	q
				d.	h.	° ′	° ′	° ′	
185	158	1827 iii.	Sept.	11	6	250 57	149 39	54 4	0·1378
186	(105)	1829	Jan.	9	17	157 17	334 29	13 20	0·3455
187	159	1830 i.	April	9	7	212 11	206 21	21 16	0·9214
188	160	— ii.	Dec.	27	15	310 59	337 53	44 45	0·1258
189	(105)	1832 i.	May	3	23	157 21	334 32	13 22	0·3434
190	161	— ii.	Sept.	25	12	227 55	72 27	43 18	1·1839
191	(92)	— iii.	Nov.	26	2	110 0	248 15	13 13	0·8790
192	162	1833	Sept.	10	4	222 51	323 0	7 21	0·4584
193	163	1834	April	2	15	276 33	226 48	5 56	0·5150
194	164	1835 i.	March	27	13	207 42	58 19	9 7	2·0413
195	(105)	— ii.	Aug.	26	8	157 23	334 34	13 21	0·3444
196	(4)	— iii.	Nov.	15	22	304 31	55 9	17 45	0·5865
197	(105)	1838	Dec.	19	0	157 27	334 36	13 21	0·3440
198	165	1840 i.	Jan.	4	10	192 11	119 57	53 5	0·6184
199	166	— ii.	March	13	2	80 12	236 50	59 12	1·2204
200	(16)	— iii.	April	2	12	324 20	186 4	79 51	0·7420
201	167	— iv.	Nov.	13	15	22 31	248 56	57 57	1·4808
202	(105)	1842 i.	April	12	0	157 29	334 39	13 20	0·3450
203	168	— ii.	Dec.	15	22	327 17	207 49	73 34	0·5044
204	169	1843 i.	Feb.	27	9	278 39	1 12	35 41	0·0055
205	170	— ii.	May	6	1	281 29	157 14	52 44	1·6163
206	171	— iii.	Oct.	17	3	49 34	209 29	11 22	1·6925

185. At one time supposed to be a return of the comet of 1780 (i). An elliptic orbit; period assigned, 2611 years.

186. An apparition of *Encke's comet*, afterwards visible to the naked eye.

187. Discovered in the southern hemisphere. Visible to the naked eye, with a tail 8° long.

188. Visible to the naked eye, with a tail $2\frac{1}{2}$° long.

189. An apparition of *Encke's comet*. Discovered by Henderson, June 2. Only one observation was made in Europe.

190. Discovered by Harding, July 29.

191. The first predicted apparition of *Biela's comet*.

193. Discovered by Dunlop, March 16.

195. An apparition of *Encke's comet*. Discovered by Boguslawski, July 30.

196. The second predicted return of *Halley's comet*. It was visible to the naked eye during the whole of October, with a tail from 20° to 30° long.

197. An apparition of *Encke's comet*. Discovered by Galle, Sept. 16. Perceptible to the naked eye, Nov. 7.

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·99927	–	Clüver	1827, Aug. 2	Pons	10 weeks.
0·84462	+	Encke	1828, Oct. 13	Struve	15 weeks.
0·99938	+	Hädenkamp and Mayer	1830, March 16	D'Abbadie	22 weeks.
1·0	–	Wölfers	1831, Jan. 7	Herepath	9 weeks.
0·84541	+	Encke	1832, June 1	Mossotti	?
1·0	–	C. A. Peters	— July 19	Gambart	4 weeks.
0·75146	+	Santini	— Aug. 25	Dumouchel	18 weeks.
1·0	+	C. A. Peters	1833, Oct. 1	Dunlop	2 weeks.
1·0	+	Petersen	1834, March 8	Gambart	6 weeks.
1·0	–	W. Bessel	1835, April 20	Boguslawski	5 weeks.
0·84503	+	Encke	— July 22	Kreil	9 weeks.
0·96739	–	Westphalen	— Aug. 6	Dumouchel	41 weeks.
0·84517	+	Encke	1838, Aug. 14	Boguslawski	16 weeks.
1·00020	+	Peters, Struve	1839, Dec. 3	Galle	10 weeks.
0·99323	–	Loomis	1840, Jan. 25	Galle	9 weeks.
1·0	+	Petersen	— March 6	Galle	3 weeks.
0·96985	+	Götze	— Oct. 27	Bremiker	16 weeks.
0·84479	+	Encke	1842, Feb. 8	Galle	15 weeks.
1·0	–	Petersen	— Oct. 28	Laugier	4 weeks.
0·99989	–	Hubbard	1843, Feb. 28	Many observers.	7 weeks.
1·00017	+	Götze	— May 2	Mauvais	21 weeks.
0·55596	+	Le Verrier	— Nov. 22	Faye	20 weeks.

198. Perceptible to the naked eye, Jan. 8.

199. An elliptic orbit; period assigned, 2423 years. Plantamour, however, makes it 13,864 years.

200. Probably a return of the comet of 1097. It had a tail 5° long.

201. An elliptic orbit; period assigned, 344 years, subject to an uncertainty of about 8 years. Possibly a return of the comet of 1490.

202. An apparition of *Encke's comet.*

203. Small and faint.

204. One of the finest comets of the present century. It had a tail 60° long. The orbit is remarkable for its small perihelion distance. The period assigned is 376 years. This may be a return of the comet of 1668, but many others have also been supposed to be identical with it. (See Cooper's *Cometic Orbits*, pp. 162–9.)

206. Usually known as *Faye's comet.* It had a very small tail. Period, 7·44 years.

No.	No.	Year.	PP.			ϖ	☊	ι	q
				d.	h.	° ′	° ′	° ′	
207	(53?)	1844 i.	Sept.	2	11	342 30	63 49	2 54	1·1864
208	172	— ii.	Oct.	17	8	180 24	31 39	48 36	0·8553
209	173	— iii.	Dec.	13	16	296 0	118 23	45 36	0·2512
210	174	1845 i.	Jan.	8	3	91 19	336 44	46 50	0·9051
211	175	— ii.	April	21	0	192 33	347 6	56 23	1·2546
212	(44)	— iii.	June	5	16	262 2	337 48	48 41	0·4016
213	(105)	— iv.	Aug.	9	15	157 44	334 19	13 7	0·3381
214	176	1846 i.	Jan.	22	2	89 6	111 8	47 26	1·4807
215	(92)	— ii.	Feb.	10	23	109 2	245 54	12 34	0·8564
216	177	— iii.	Feb.	25	7	116 28	102 37	30 57	0·6500
217	178	— iv.	March	5	12	90 27	77 33	85 6	0·6637
218	179	— v.	May	27	21	82 32	161 18	57 35	1·3762
219	180	— vi.	June	1	5	240 7	260 28	30 24	1·5287
220	181	— vii.	June	5	12	162 0	261 51	29 18	0·6334
221	182	— viii.	Oct.	29	17	98 35	4 41	49 41	0·8306
222	183	1847 i.	March	30	6	276 2	21 42	48 39	0·0425
223	184	— ii.	June	4	18	141 34	173 56	79 34	2·1161
224	185	— iii.	Aug.	9	8	21 17	76 43	32 38	1·4847
225	186	— iv.	Aug.	9	10	246 41	338 17	83 27	1·7671
226	187	— v.	Sept.	9	13	79 12	309 48	19 8	0·4879
227	188	— vi.	Nov.	14	9	274 14	190 50	71 53	0·3291
228	189	1848 i.	Sept.	8	1	310 34	211 32	84 24	0·3199
229	(105)	— ii.	Nov.	26	2	157 47	334 22	13 8	0·3370

207. Visible to the naked eye. An elliptic orbit; period assigned, 5·469 years. It has not been observed since. Possibly identical with the comet of 1678.

208. Discovered by D'Arrest, July 9. Visible to the naked eye, Nov. 10. Period, 102,050 years, subject to an uncertainty of 3090 years.

209. First seen in the southern hemisphere. It had a tail 10° long.

211. Discovered by Faye, March 6.

212. Discovered by Richter, June 6. A fine comet. Visible to the naked eye, with a tail 2½° long. A return of the comet of 1596. Period, 250 years.

213. An apparition of *Encke's comet*. Discovered by Di Vico, July 9, and by Coffin, July 10.

214. An elliptic orbit; period assigned, 2721 years.

215. An apparition of *Biela's comet*. Discovered by Galle, Nov. 28. It was at this return that the comet separated into 2 parts.

216. An elliptic orbit; period assigned, 5·58 years.

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·61765	+	Brünnow	1844, Aug. 22	Di Vico	19 weeks.
0·99960	−	Plantamour	— July 7	Mauvais	35 weeks.
1·0	+	Hind	— Dec. 19	Wilmot	12 weeks.
1·0	+	Götze	— Dec. 28	D'Arrest	13 weeks.
1·0	+	Faye	1845, Feb. 25	Di Vico	9 weeks.
0·98987	−	D'Arrest	— June 2	Colla	4 weeks.
0·84743	+	Encke	— July 4	Walker	10 days.
0·99240	+	Jelinek	1846, Jan. 24	Walker	14 weeks.
0·75700	+	Plantamour	1845, Nov. 26	Walker	21 weeks.
0·79446	+	Hind	1846, Feb. 26	Brorsen	8 weeks.
0·96224	+	Peirce	— Feb. 20	Di Vico	10 weeks.
1·0	−	Argelander	— July 29	Di Vico	11 weeks.
0·72133	−	C. H. Peters	— June 26	C. H. Peters	4 weeks.
0·98836	−	Wichmann	— April 30	Brorsen	6 weeks.
1·0	+	Hind	— Sept. 23	Di Vico	3 weeks.
1·0	+	Pogson	1847, Feb. 6	Hind	11 weeks.
1·0	−	Von Littrow	— May 7	Colla	30 weeks.
1·0	−	Schweitzer	— Aug. 31	Schweitzer	13 weeks.
1·0	−	Von Littrow	— July 4	Mauvais	41 weeks.
0·97256	+	D'Arrest	— July 20	Brorsen	8 weeks.
1·0	−	D'Arrest	— Oct. 1	Miss Mitchell	13 weeks.
1·0	−	Sonntag and Quirling	1848, Aug. 7	Petersen	3 weeks.
0·84782	+	Encke	— Aug. 27	G. P. Bond	13 weeks.

217. Discovered by G. P. Bond, Feb. 26.
218. Discovered by Hind, 2 hours later.
219. Discovered by Di Vico, July 2. An elliptic orbit; period assigned, 12·8 years, subject to an uncertainty of 1 year.
220. Discovered by Wichmann, May 1. Visible to the naked eye, May 14. An elliptic orbit; period assigned, 400 years.
222. Visible in the daytime. It had a tail $1\frac{1}{2}°$ long. The true elements are probably elliptical. Hornstein has throughly discussed the orbit of this comet.
225. A parabolic orbit best satisfies the observations.
226. Period assigned, 75 years.
227. Discovered by Di Vico, Oct. 3; by Dawes, Oct. 7; and by Madame Rümker, Oct. 11.
229. An apparition of *Encke's comet*. Discovered by Hind, Sept. 13. Perceptible to the naked eye, Oct. 6. On Nov. 3 it had a tail more than 1° long.

No.	No.	Year.	PP.			ϖ		☊		ι		q
				d.	h.	°	′	°	′	°	′	
230	190	1849 i.	Jan.	19	8	63	11	215	10	85	4	0·9599
231	191	— ii.	May	26	11	235	43	202	33	67	9	1·1593
232	192	— iii.	June	8	4	267	3	30	31	66	59	0·8946
233	193	1850 i.	July	23	12	273	24	92	53	68	12	1·0815
234	194	— ii.	Oct.	19	8	89	20	206	0	40	6	0·5647
235	(171)	1851 i.	April	3	11	49	42	209	30	11	21	1·6999
236	195	— ii.	July	9	0	324	10	149	19	14	14	1·1847
237	196	— iii.	Aug.	26	5	310	58	223	40	38	9	0·9843
238	197	— iv.	Sept.	30	19	338	45	44	28	74	0	0·1410
239	(105)	1852 i.	March	14	18	157	51	334	23	13	7	0·3374
240	198	— ii.	April	19	13	280	0	317	8	48	52	0·9050
241	(92)	— iii.	Sept.	23	1	109	8	245	52	12	33	0·8606
242	199	— iv.	Oct.	12	15	43	12	346	13	40	58	1·2510
243	200	1853 i.	Feb.	24	6	153	21	69	49	20	19	1·0938
244	201	— ii.	May	9	16	201	53	40	57	57	44	0·9044
245	202	— iii.	Sept.	1	17	310	56	140	31	61	31	0·3068
246	203	— iv.	Oct.	16	14	302	7	220	4	61	1	0·1725
247	204	1854 i.	Jan.	4	6	55	57	227	3	66	7	1·2002
248	205	— ii.	March	24	0	213	47	315	26	82	22	0·2770
249	(13)	— iv.	June	22	2	272	58	347	48	71	8	0·6475
250	206	— v.	Oct.	27	9	94	20	324	34	40	59	0·8001

230. A parabolic orbit satisfies the observation, but a period of 382,801 years has been assigned ! ! !

231. It had a small tail.

232. Discovered a few hours later by Bond, and by Graham April 14. Period, 8375 years.

233. Visible to the naked eye, with a tail. Carrington has assigned a period of about 29,000 years.

234. Discovered by Brorsen, Sept. 5; by Mauvais and Robertson, Sept. 9; and by Clausen, Sept. 14.

235. The first predicted apparition of *Faye's comet.*

236. Period, 6·441 years.

237. Discovered by Schweitzer, Aug. 21. Period assigned, 5544 years.

238. It had a tail more than 1° long, and also a shorter one turned towards the Sun.

239. An apparition of *Encke's comet.*

240. Discovered by Petersen, May 17, and by G. P. Bond, May 19. It was very small and faint.

241. An apparition of *Biela's comet.* Theoretical elements.

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Pogson	1848, Oct. 26	Petersen	20 weeks.
1·0	+	Goujon	1849, April 15	Goujon	24 weeks.
0·99783	+	D'Arrest	— April 11	Schweitzer	20 weeks.
1·0	+	Villarceau	1850, May 1	Petersen	17 weeks.
1·0	+	Reslhüber	— Aug. 29	G. P. Bond	9 weeks.
0·55501	+	Le Verrier	— Nov. 28	Challis	14 weeks.
0·70001	+	D'Arrest	1851, June 27	D'Arrest	17 weeks.
0·99685	+	Brorsen	— Aug. 1	Brorsen	8 weeks.
1·0	+	J. Breen	— Oct. 22	Brorsen	4 weeks.
0·84767	+	Encke	1852, Jan. 9	Hind	8 weeks.
1·0	—	Sonntag	— May 15	Chacornac	3 weeks.
0·756225	+	Santini	— Aug. 25	Secchi	5 weeks.
0·92475	+	Marth	— June 27	Westphal	24 weeks.
1·0	—	D'Arrest	1853, March 6	Secchi	3 weeks.
1·0	—	Bruhns	— April 4	Schweitzer	10 weeks.
1·00002	+	Krahl	— June 10	Klinkerfues	7 months.
1·0	—	Bruhns	— Sept. 11	Bruhns	11 weeks.
1·0	—	Marth	— Nov. 25	Van Arsdale	12 weeks.
1·0	—	Hornstein	1854, March 23	Many observers	6 weeks.
1·0	—	Bruhns	— June 4	Klinkerfues	10 weeks.
1·0	+	Bruhns	— Sept. 11	Klinkerfues	11 weeks.

242. Discovered also by C. H. Peters. Visible to the naked eye early in October. Period, 70 years.

243. Discovered by Schweitzer and C. W. Tuttle, March 8, and by Hartwig, March 10. Elements resemble those of the comet of 1664.

244. Visible to the naked eye in the beginning of May, with a tail 3° long.

245. Visible in the daytime, Aug. 31 to Sept. 4. In the south of Europe, a tail 15° long was seen.

246. Perceptible to the naked eye about the middle of the month. Elements resemble those of the comet of 1582.

247. Discovered by Klinkerfues, Dec. 2.

248. First seen in the south of France, when very conspicuous, with a tail 4° long. Elements resemble those of the comet of 1799 (ii).

249. Discovered also by Van Arsdale. At the time of the PP it was visible to the naked eye. The elements strongly resemble those of the comets of 961 and 1558.

250. Discovered also by several other observers. Probably a return of the comet of 1845 (i).

No.	No.	Year.	PP.			ϖ	☊	ι	q
				d.	h.	° ′	° ′	° ′	
251	207	1854 vi.	Dec.	16	1	165 52	238 19	14 10	1·3673
252	208	1855 i.	Feb.	5	17	226 33	189 40	51 12	1·2195
253	(22)	— iii.	May	30	5	237 36	260 15	23 7	0·5678
254	(105)	— iv.	July	1	5	157 53	334 26	13 8	0·3371
255	209	— v.	Nov.	25	15	85 21	52 2	10 16	1·2248
256	210	1857 i.	March	21	8	74 49	313 12	87 57	0·7721
257	(177)	— ii.	March	29	5	115 48	101 53	29 45	0·6202
258	211	— iii.	July	17	23	249 37	23 40	58 59	0·3675
259	212	— iv.	Aug.	24	0	21 46	200 49	32 46	0·7427
260	213	— v.	Sept.	30	19	250 21	14 46	56 18	0·5651
261	214	— vi.	Nov.	19	1	44 15	139 18	37 50	1·1009
262	(195)	— vii.	Dec.	33	0	323 3	148 27	13 56	1·1696
263	(111)	1858 i.	Feb.	23	8	115 29	268 54	54 32	1·0274
264	(141)	— ii.	May	2	1	275 38	113 32	10 48	0·7689
265	215	— iii.	May	2	1	195 42	171 3	23 11	1·2090
266	216	— iv.	June	5	4	226 6	324 21	80 28	0·5462
267	(171)	— v.	Sept.	12	14	49 49	209 45	11 21	1·6999
268	217	— vi.	Sept.	29	23	36 13	165 19	63 1	0·5784
269	218	— vii.	Oct.	12	19	4 13	159 45	21 16	1·4270
270	(105)	— viii.	Oct.	18	8	157 57	334 28	13 4	0·3407
271	219	1859 ii.	May	29	5	75 9	357 7	84 9	0·2020
272	220	1860 i.	Feb.	16	17	173 45	324 3	79 35	1·1973

251. Discovered by Winnecke and Dien, Jan. 15, 1855.
253. Discovered also by Dien and Klinkerfues. Probably a return of the comet of 1362 (i). Period assigned, 493 years.
254. An apparition of *Encke's comet.*
255. Discovered also by Van Arsdale.
256. Discovered also by Van Arsdale. Orbit decidedly parabolic.
257. An apparition of *Brorsen's comet*, 1846 (iii).
259. Discovered by Dien, July 28, and by Habicht, July 30. An elliptic orbit; period assigned, 234 years.
260. Faintly perceptible to the naked eye, Sept. 20. It had a short tail. Elements resemble those of the comets of 1790 (iii) and 1825 (i). A period of 1618 years has been assigned by Villarceau.
261. Discovered a few hours later by Van Arsdale.
262. An apparition of *D'Arrest's comet.* Period, 2366 days. Lind and Villarceau concur in dating the PP for Nov. 28.

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility
1·0	+	Oudemans	1854, Dec. 24	Colla	16 weeks.
1·0	–	Winnecke	1855, April 11	Schweitzer	5 weeks.
0·99090	–	Donati	— June 3	Donati	2 weeks.
0·84778	+	Encke	— July 13	Maclear	5 weeks.
1·0	–	G. Rümker	— Nov. 12	Bruhns	7 weeks.
1.0	+	Pape	1857, Feb. 22	D'Arrest	9 weeks.
0·80160	+	Bruhns	— Mar. 18	Bruhns	11 weeks.
1·0	–	Pape	— June 22	Klinkerfues	3 weeks.
0·98037	+	Möller	— July 25	C. H. Peters	5 weeks.
1·0	–	Bruhns	— Aug. 20	Klinkerfues	7 weeks.
1·0	–	Pape	— Nov. 10	Donati	5 weeks.
0·65985	+	Schulze	— Dec. 5	Maclear	6 weeks.
0·82961	+	Bruhns	1858, Jan. 4	H. P. Tuttle	9 weeks.
0·75467	+	Winnecke	— Mar. 8	Winnecke	12 weeks.
1·0	+	Hall	— May 2	Tuttle	4 weeks.
1·0	–	Bruhns	— May 21	Bruhns	3 weeks.
0·55501	+	Bruhns	— Sept. 8	Bruhns	8 weeks.
0·99620	–	Von Asten	— June 2	Donati	7½ months.
1·0	–	Weiss	— Sept. 5	H. P. Tuttle	8 weeks.
0·84639	+	Powalky	— Aug. 7	Förster	10 weeks.
1·0	–	Hall	1859, April 2	Tempel	12 weeks.
1·0	+	Liais	1860, Feb. 26	Liais	2 weeks.

263. Discovered by Bruhns, Jan. 11. Probably a return of the comet of 1790 (i Period assigned, 13·6 years.

264. An apparition of the comet of 1819 (iii), now called *Winnecke's Comet.*

266. Elements resemble those of the comet of 1799 (ii).

267. An apparition of *Faye's comet.*

268. One of the finest comets of the present century. It became visible to t naked eye early in September, and was very conspicuously seen in Europe for abo 6 weeks, when, owing to its rapid passage to the southern hemisphere, it becan lost to view. It was seen at the Cape of Good Hope till March 4, 1859. Duri the first week in October it had a tail nearly 40° long. An elliptic orbit; peri assigned, 1879 years.

270. An apparition of *Encke's comet.* It was very faint.

272. It does not appear that this comet was seen in Europe. Liais, who observ it in Brazil, states that it had a double nebulosity, and conjectures it to be identic with 1845 (ii), 1785 (i), and 1351.

No.	No.	Year.	PP.			π	☊	ι	q
				d.	h.	° ′	° ′	° ′	
273	221	1860 ii.	March	5	17	50 16	8 56	48 13	1·3083
274	222	— iii.	June	16	2	161 32	84 40	79 18	0·2929
275	223	— iv.	Sept.	28	7	111 59	104 14	28 14	0·9537
276	224	1861 i.	June	3	8	243 22	29 55	79 45	0·9207
277	225	— ii.	June	11	12	249 4	278 58	85 26	0·8223
278	226	— iii.	Dec.	7	3	173 30	145 6	41 57	0·8391
279	(105)	1862 i.	Feb.	6	4	158 0	334 30	13 5	0·3399
280	227	— ii.	June	22	1	299 20	326 32	7 54	0·9813
281	228	— iii.	Aug.	22	22	344 41	137 26	66 25	0·9626
282	229	— iv.	Dec.	28	3	125 9	355 44	42 22	0·8025
283	230	1863 i.	Feb.	3	12	191 22	116 55	85 22	0·7947
284	231	— ii.	April	4	22	247 15	251 16	67 22	1·0682
285	232	— iii.	April	20	21	305 47	250 10	85 29	0·6288
286	233	— iv.	Nov.	9	12	94 43	97 29	78 5	0·7066
287	(129)	— v.	Dec.	26	14	59 13	304 57	63 35	0·7661
288	234	— vi.	Dec.	29	4	183 8	105 1	83 18	1·3131
289	235	1864 i.	July	27	21	190 10	175 11	44 56	0·6140
290	236	— ii.	Aug.	15	14	304 13	95 12	1 52	0·9092
291	237	— iii.	Oct.	11	8	159 30	31 43	70 13	0·9338
292	238	— iv.	Dec.	22	11	321 42	203 13	48 52	0·7709
293	239	— v.	Dec.	27	18	162 22	340 53	17 7	1·1145
294	240	1865 i.	Jan.	14	7	141 15	253 3	87 32	0·0260

274. Suddenly became visible towards the end of June. On the 22nd it had a tail 15° long. Liais has assigned a period of 1089 years.

275. Very faint, and only 4 observations obtained.

276. Visible to the naked eye; it had a faint diffused tail 3° long: an elliptic orbit; period assigned 415·4 years.

277. One of the most magnificent comets on record: on July 2 its tail was more than 100° long. An elliptic orbit; period assigned, 419 years.

279. An apparition of *Encke's comet.*

280. Discovered by Schmidt and Tempel on July 2; on July 4 it had a tail ½° long, and was then visible to the naked eye: between July 3rd and 4th it traversed 24° of a great circle.

281. Discovered by H. P. Tuttle and Simmons, July 18; by Pacinotti, July 22; and by Rosa, July 25. Conspicuously visible to the naked eye for 2 or 3 weeks in

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Seeling	1860, April 17	C. Rümker	7 weeks.
1·0	+	Moësta	— June 19	Several observers	8 weeks.
1·0	+	Oppolzer	— Oct. 23	Tempel	3 days.
0·98345	+	Oppolzer	1861, April 4	Thatcher	8 weeks.
0·98532	+	Seeling	— May 13	Tebbutt	12 months.
1·0	—	Pape	— Dec. 28	H. P. Tuttle	8 weeks.
0·84670	+	Powalky	— Sept. 28	Förster	17 weeks.
1·0	—	Seeling	1862, July 1	Valz	4 weeks.
0·96127	—	Oppolzer	— July 15	Swift	13 weeks.
1·0	—	Engelmann	— Nov. 30	Bruhns	3 weeks.
1·0	+	Engelmann	— Nov. 27	Respighi	15 weeks.
1·0	—	Raschkoff	1863, April 11	Klinkerfues	6 months.
1·0	+	Frischauf	— April 12	Respighi	5 weeks.
1·0	+	Oppolzer	— Nov. 4	Tempel	16 weeks.
0·94590	+	Weiss	— Dec. 28	Respighi	8 weeks.
1·0	+	Engelmann	— Oct. 9	Bäcker	6 months.
1·0	—	Celoria	1864, Sept. 9	Donati	4 weeks.
1·0	—	Kowalczyk	— July 4	Tempel	14 weeks.
1·0	—	Engelmann	— July 23	Donati	6 months.
1·0	+	Tietjen	— Dec. 15	Bäcker	7 weeks.
1·0	—	Engelmann	— Dec. 30	Bruhns	4 weeks.
1·0	—	Tebbutt	1865, Jan. 18	Moësta	10 weeks.

August—September; with a tail, on Aug. 27, as much as 25° long, according to Schmidt. An elliptic orbit; period assigned, 123 years.

283. Discovered by Bruhns, Nov. 30.

284. Visible to the naked eye in May: it had a faint tail 3° long.

285. Visible to the naked eye as a 5th mag. star.

286. Discovered independently by J. F. Schmidt, Nov. 12. Visible to the naked eye as a star of the 4th mag., with a tail 2° or more long.

287. Discovered also by Bäcker, Jan. 1, 1864. Visible to the naked eye, with a tail ½° long, at the end of January. Believed to be a return of the comet of 1810, and possibly identical with that of 1490.

288. Discovered by Tempel, Oct. 14. Two computers make the orbit a hyperbola.

290. The same computer subsequently obtained an elliptic orbit with a period of 4754 years.

294. Seen only in the southern hemisphere. On Jan. 18 it had a tail 25° long.

No.	No.	Year.	PP.		ϖ	☊	ι	q
				d. h.	° ′	° ′	° ′	
295	(171)	1865 iii.	Oct.	3 23	49 56	209 41	11 22	1·6822
296	241	1866 i.	Jan.	11 3	60 28	231 26	17 18	0·9765
297	242	1867 i.	Jan.	19 20	75 52	78 35	18 12	1·5725
298	243	— ii.	May	23 22	236 9	101 10	6 24	1·2870
299	244	— iii.	Nov.	6 23	276 21	64 58	83 26	0·3304
300	(177)	1868 i.	April	20 23	116 2	101 14	29 22	0·5968
301	245	— ii.	June	25 23	287 7	53 40	48 11	0·5823
302	(105)	— iii.	Sept.	14 16	158 10	334 31	13 6	0·3339
303	(141)	1869 i.	June	10 23	275 55	113 33	10 48	0·7815
304	246	— ii.	Oct.	9 18	123 24	311 29	68 23	1·2306
305	247	— iii.	Nov.	20 19	41 17	292 40	6 55	1·1026
306	248	1870 i.	July	14 1	303 32	141 44	58 12	1·0087
307	249	— ii.	Sept.	2 12	17 49	12 56	80 34	1·8171
308	(195)	— iii.	Sept.	23	318 41	146 25	15 39	1·2803
309	250	— iv.	Dec.	19 21	4 8	94 44	32 43	0·3892
310	251	1871 i.	June	10 14	141 49?	279 18	87 36	0·6543
311	252	— ii.	July	27 0	115 43	211 56	78 0	1·0835
312	(111)	— iii.	Nov.	30	116 5	269 17	54 17	1·0301
313	253	— iv.	Dec.	20 8	147 2	264 30	81 36	0·6944
314	(105)	— v.	Dec.	28 18	158 12	334 34	13 8	0·3329
315	(243)	1873 i.	May	9 18	238 1	78 43	9 46	1·2872
316	254	— ii.	June	25 8	306 4	120 54	12 44	1·3436
317	(171)	— iii.	Aug.	2 23	50 2	209 39	11 21	1·6828
318	255	— iv.	Sept.	10 18	36 57	230 38	84 3	0·7948

295. An apparition of *Faye's comet.*
296. An elliptic orbit; period assigned, 53 years. Probably a meteor comet.
297. An elliptic orbit; period assigned, 33·62 years.
298. Usually known as *Tempel's comet.*
299. Discovered 4 hours later by Winnecke.
300. An apparition of *Brorsen's comet.* Tempel believes he sighted the comet as early as March 22.
303. An apparition of *Winnecke's comet,* 1819 (iii).
306. It had a very short tail.
308. An apparition of *D'Arrest's comet.*

e	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·55753	+	Möller	1865, Aug. 22	Thiele	17 weeks.
0·90541	−	Oppolzer	— Dec. 19	Tempel	7 weeks.
0·84905	+	Searle	1867, Jan. 28	Tempel	10 weeks.
0·50967	+	Sandberg	— April 3	Tempel	16 weeks.
1·0	−	Oppolzer	— Sept. 27	Bäcker	5 weeks
0·80809	+	Bruhns	1868, April 11	Tempel	7 weeks.
1·0	−	W. E. Plummer	— June 13	Winnecke	3 weeks.
0·84916	+	Von Asten	— July 14	Winnecke	6 weeks.
0·75194	+	Oppolzer	1869, April 9	Winnecke	6 months.
1·0	−	Oppenheim	— Oct. 11	Tempel	4 weeks.
1·0	+	Bruhns	— Nov. 27	Tempel	5 weeks.
1·0	−	Dreyer	1870, May 29	Winnecke	6 weeks.
1·0	−	Hind	— Aug. 28	Coggia	17 weeks.
0·63490	+	Leveau	— Aug. 31	Winnecke	16 weeks.
1·0	−	Schulhof	— Nov. 23	Winnecke	1 week.
0·99781	+	Holetschek.	1871, April 7	Winnecke	6 weeks.
1·0	−	Schulhof	— June 14	Tempel	13 weeks.
0·82105	+	Tischler	— Oct. 12	Borrelly	5 weeks.
1·0	−	Schulhof	— Nov. 3	Tempel	15 weeks.
0·84936	+	Glasenapp	— Sept. 19	Winnecke	11 weeks.
0·51738	+	Hind	1873, April 3	Stephan	7 weeks.
0·54978	+	Schulhof	— July 3	Tempel	12 weeks.
0·55738	+	Möller	— Sept. 3	Stephan	12 weeks.
1·0	−	W. E. Plummer	— Aug. 20	Borrelly	4 weeks.

310. Discovered by Borrelly on Apr. 13, and L. Swift on Apr. 15. It had a small tail. An elliptic orbit; period assigned, 5188 years.

311. Thought to be a return of the comet of 1827 (i).

312. An apparition of *Tuttle's comet,* 1858 (i).

314. An apparition of *Encke's comet.* Guessed at, rather than certainly viewed on Sept. 19. First fairly seen by Dunér on Oct. 4, and by Hind on Oct. 8.

315. An apparition of *Tempel's comet,* 1867 (ii).

316. An elliptic orbit; period assigned, 5·158 years.

317. An apparition of *Faye's comet.*

No.	No.	Year.	PP.	ϖ	☊	ι	q
			d. h.	° ′	° ′	° ′	
319	256	1873 v.	Oct. 1 18	302 58	176 43	58 30	0·3848
320	(177)	— vi.	Oct. 10 12	116 5	101 15	29 23	0·5935
321	(137?)	— vii.	Dec. 1 5	85 43	250 19	30 1	0·7344
322	257	1874 i.	March 9 22	300 36	31 31	58 17	0·0439
323	258	— ii.	March 14 0	302 15	274 7	31 32	0·8861
324	259	— iii.	July 8 20	271 7	118 44	66 21	0·6757
325	260	— iv.	July 19 0	6 50	216 13	34 29	1·7105
326	261	— v.	Aug. 27 3	344 9	251 29	41 50	0·9827
327	262	— vi.	Oct. 18 16	264 29	281 38	80 34	0·5197
328	(141)	1875 i.	March 11 0	276 42	111 34	11 17	0·7815
329	(105)	— ii.	April 13				

320. An apparition of *Brorsen's comet.*

321. Discovered by Winnecke on Nov. 11. Probably identical with the comet of 1818 (i); but doubtful whether period is 55·8, 18·6, or 6·2 years; the latter Prof. Weiss thinks the more probable.

324. An elliptic orbit; period assigned, 10,445 years.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	−	W. E. Plummer	1873, Aug. 23	Henry	13 weeks.
0·80890	+	W. E. Plummer	— Aug. 31	Stephan	7 weeks.
1·0	+	Weiss	— Nov. 10	Coggia	1 week.
1·0	+	Schulhof	1874, Feb. 20	Winnecke	1 week.
1·0	+	Schur	— April 11	Winnecke	9 weeks.
0·99859	+	Geelmuden	— April 17	Coggia	6 months.
1·0	+	Holetschek	— July 25	Coggia	9 weeks.
0·99923	+	Grützmacher	— Aug. 19	Borrelly	7 weeks.
1·0	−	Holetschek	— Dec. 7	Borrelly	2 weeks.
0·74101	+	Oppolzer	1875, Feb. 1	Littrow	
	+		— Jan. 26	Holden	

326. Perihelion passage doubtful—probably the first week in July—and therefore *perhaps* before that of No. 324. An elliptic orbit.
328. An apparition of *Winnecke's comet*, 1819 (iii).
329. An apparition of *Encke's comet*.

A SUMMARY OF THE PRECEDING CATALOGUE[a].

FROM an examination of the Catalogue just given we may obtain certain results which will here be analysed.

It appears that 329 comet apparitions have been subjected to mathematical investigation, viz.:—

Known periodical comets	20
Subsequent returns	66
Elliptic orbits not yet verified	43
Parabolic comets	194
Hyperbolic comets	6
	329

Of known periodical comets, we have the following, as the number of the apparitions of each:—

20	of Encke's
17	of Halley's
6	of Biela's
5	of Faye's
4 each	of Brorsen's and Winnecke's
3 each	of D'Arrest's and Tuttle's
2	of Tempel's

and 2 of each of the following:—

961: 1097: 1231: 1264: 1362 i: 1532: 1596: 1678: 1699 i: 1790 iii: 1810.

Elliptic orbits have been assigned *in the Catalogue* to various comets, of which however no 2nd returns have as yet taken place.

Elliptic orbits have been assigned by some computers to the following comets; but the probability is not sufficiently great to warrant their being included in a list of elliptic comets:—

1585: 1744: 1773: 1826 ii: 1832 ii: 1846 viii: 1847 i: 1847 iii: 1849 i: 1850 i: 1857 v: 1860 iii.

[a] This summary does not include comets *discovered subsequently* to Oct. 1, 1876. The omission is quite immaterial as regards the general results.

The following are the known hyperbolic comets:—

1729: 1771: 1774: 1840 i: 1843 ii: 1853 iii.

Hyperbolic orbits have been assigned by some computers to the following comets: but the probability is not sufficiently great to warrant their being definitely given as such:—

1723: 1773: 1779: 1818 iii: 1826 ii: 1830 i: 1843 i: 1844 iii: 1845 i: 1845 ii: 1849 iii: 1852 ii: 1863 vi.

The following have been supposed by some to be identical:—

1873 vii.	with	1818 i.
1871 ii.	—	1827 i.
1863 v.	—	1490.
1860 i.	—	1845 ii, 1785 i, and 1351.
1858 iv.	—	1799 ii.
1857 v.	—	1825 i, and 1790 iii.
1854 iv.	—	1558.
1854 ii.	—	1799 ii.
1853 iv.	—	1582 ii.
1853 i.	—	1664.
1852 ii.	—	1819 ii.
1844 i.	—	1678.
1843 i.	—	1668 and many others.
1840 iv.	—	1490.
1827 iii.	—	1780 i.
1819 iv.	—	1743 i.
1819 iii.	—	1766 ii.
1661	—	1532.

CLASSIFICATION OF THE DIRECTIONS OF HELIOCENTRIC MOTION.

I.

Of the 20 known elliptic comets, there are, whose motion is—

Direct	14	or 70 per cent.
Retrograde	6	or 30 „
	20	

II.

Of the 43 unverified elliptic comets, there are, whose motion is—

Direct	29	or 67·4 per cent.
Retrograde	14	or 32·6 „
	43	

III.

Of the 12 doubtful elliptic comets, there are, whose motion is—

Direct	9 or 75 per cent.	
Retrograde	3 or 25	,,
	12	

IV.

Of the 6 known hyperbolic comets all have a direct motion.

V.

Of the 13 improbable hyperbolic comets, there are, whose motion is—

Direct	9 or 69·2 per cent.	
Retrograde	4 or 30·8	,,
	13	

VI.

Then of the remaining 194 comets, probably parabolic (I here include Classes III. and V.), there are, whose motion is—

Direct	78 or 40·2 per cent.	
Retrograde	112 or 57·8	,,
Unknown	4 or 2·0	,,
	194	

Combining Classes I. II. IV. and VI., we get—

Direct	127 or 48·2 per cent.	
Retrograde	132 or 50·1	,,
Unknown	4 or 1·7	,,
	263	

An examination of the preceding shews, *That with comets revolving in elliptic orbits, there is a strong and decided tendency to direct motion; the same obtains with the hyperbolic orbits; with the parabolic orbits, there is a rather large preponderance the other way; and taking all the calculated comets together, the numbers are too nearly equal to afford any indication of the existence of a general law governing the direction of motion.*

CLASSIFICATION OF INCLINATIONS.

Dividing the calculated comets into 4 classes, as before given, we shall find that the inclination of the orbits of every 100 are distributed as follows[b] :—

Angle of Inclination.	Class I.	Class II.	Class IV.	Class VI.	Total.
°	No. p. cent.	No. p. cent.	No. p. cent.	No. p. cent.	No. p. cent.
0—10	3 = 15	4 = 9	0	14 = 7	21 = 8
10—20	6 = 30	4 = 9	1 = 16	11 = 6	22 = 9
20—30	2 = 10	2 = 5	0	17 = 9	21 = 8
30—40	2 = 10	6 = 14	0	16 = 8	24 = 9
40—50	0 = 0	7 = 17	0	32 = 17	39 = 15
50—60	2 = 10	6 = 14	2 = 33	23 = 12	33 = 13
60—70	2 = 10	6 = 14	1 = 16	22 = 12	31 = 12
70—80	3 = 15	4 = 9	1 = 16	25 = 13	33 = 13
80—90	0 = 0	4 = 9	1 = 16	29 = 15	34 = 13
	20 : 100	43 : 100	6 : 99	189 : 99	258 : 100

An examination of the 1st column shews this fact:—

That there is a decided tendency in the periodic comets to revolve in orbits but little inclined to the ecliptic, and therefore a low inclination is an eminently favourable indication of a periodic comet.

Combining the 4 classes, we find:—*A decided disposition in the orbits to congregate in and around a plane inclined 50° to the ecliptic.*

CLASSIFICATION OF THE POSITIONS OF THE PERIHELIA AND NODAL POINTS[c].

Taking the longitudes of the perihelia and of the ascending nodes of 209 comets (deducting 8 not certainly determined), we shall find that in every 100 they are distributed as follows:—

[b] Class VI. is reduced by some comets of indeterminate inclination; hence the number 189.

[c] On the subject of coincidences in cometary orbits some curious instances noted by Hoek deserve attention (*Ast. Nach.*, vol. lxx. No. 1669. Nov. 30, 1867.)

Angular distance.	π	☊
0°— 30	7·6	7·6
30— 60	9·0	10·0
60— 90	13·0	10·5
90—120	9·9	8·0
120—150	8·0	8·0
150—180	4·2	8·5
180—210	6·6	10·5
210—240	8·8	9·6
240—270	9·9	7·1
270—300	11·4	4·3
300—330	8·5	9·6
330—360	2·8	5·7
	99·7	99·4

An examination of the 2nd column shews,—*That there is an evident tendency in the perihelia to crowd together in 2 opposite regions, between* 60°—120° *and* 240°—300°. A uniform distribution would give 16·6 perihelia to every arc of 60°. Now, in the 1st case, we have 29·9, or 38 per cent. above the mean; and in the 2nd, 21·3, or 29 per cent. above the mean. A further examination will shew that the regions between 150°—180° and 330°—360° are correspondingly poor.

From the 3rd column it appears:—*That there is an evident, though less marked, tendency in the nodes to come together in 2 regions* (*not, however, in this case exactly opposite*) *between* 30°—90° *and* 180°—240°. A uniform distribution would give 16·6 nodes to every arc of 60°. Now, in the 1st case we have 20·5, or 23 per cent above the mean; and in the 2nd, 20·1, or 20 per cent. above the mean. With the nodes the poor region seems to be between 270°—300°.

CLASSIFICATION OF THE DISTANCES OF THE PERIHELIA.

Within the radius of the Earth's orbit	193 or	73·4	per cent.
Between 1 and 2 radii	64 or	24·3	„
„ 2 and 3 „	5 or	1·9	„
„ 3 and 4 „	0 or	0·0	„
„ 4 and 5	1 or	0·4	„
Beyond 5	0 or	0·0	„
	263	100·0	

CLASSIFICATION OF THE PERIHELION PASSAGES ACCORDING TO THE MONTHS OF THE YEAR.

Of the 328 known perihelion passages there occurred in :—

January	27
February	22
March	26
April	27
May	22
June	28
July	23
August	20
September	36
October	32
November	34
December	31
	328

The monthly average is therefore 27·3. June, September, October, November and December, are above the mean; all the others below. The minimum is in August, which only exhibits 20·0, or 25 per cent below the average—a circumstance doubtless due to the long days and short nights which more or less prevail during the summer months. The quick rise in September is probably due less to the lengthening of the nights (and consequent increased opportunities for observation) than to the excellence of that month for astronomical purposes. The advantages afforded by the long winter nights are more or less neutralized by the frequent inclement weather. Thus it happens that all the winter months (December excepted) are below the average.

CHAPTER VII.

A CATALOGUE OF COMETS RECORDED, BUT NOT WITH SUFFICIENT PRECISION TO ENABLE THEIR ORBITS TO BE CALCULATED[a].

IN the present day it rarely happens that a comet becomes visible without its being observed, at any rate, sufficiently long for some approximation to the elements of its orbit to be deduced. Such however was not the case in olden times. Observers were few, and till the 17th century observatories and instruments can scarcely be said to have existed at all. Therefore whatever astronomical information we possess antecedent to A.D. 1600, we owe to the writings of historians and chroniclers, who seldom give more than bare statements, with few or no details.

The first astronomer who made any systematic attempt to put together the various allusions to comets which occur in the old writers was the French astronomer Pingré, who in 1783 published his celebrated *Cométographie; ou Traité historique et theoretique des Comètes*. This work, which for the industry and labour bestowed upon it has few equals, has been from the period of its publication down to the present day the astronomer's text-book on the subject of cometary history: it has never been superseded, and is never likely to be, though supplementary matter has of course been accumulated. E. Biot, working from Chinese sources, has followed up Pingré with great industry. The following catalogue is based upon that of Pingré, and includes recent results, especially those elaborated in a valuable catalogue commenced by Hind

[a] I should be glad to receive information calculated to render this chapter more complete. I cannot but believe that a diligent search through the journals, whether published or in MS., of modern travellers and others, would bring to light many more comets than those catalogued in this volume.

in the *Companion to the Almanac*, but remaining unfinished. Brevity being essential to this work, I have been obliged to omit much that was curious and interesting, and to confine my attention chiefly to necessary facts and figures, with references only to the most important authorities.

The Chinese observations, to which such constant reference is made, were originally made known in Europe by MM. Couplet, Gaubil, and De Mailla, Jesuit priests at Pekin, early in the 18th century, who made very good use of their opportunities of benefiting science. De Mailla's MSS. were published at Paris in the last century, but those of Gaubil and Couplet remain in their original form. E. Biot, some years ago, published in the *Connaissance des Temps* a translation of some valuable Chinese catalogues of comets[b], which have been duly consulted; and it is not improbable that as our intercourse with that remarkable people becomes greater, further sources of information may be opened to us.

Biot gives 2 supplementary catalogues of "extraordinary stars." These are distinct in the originals from the comets strictly so called; but as there is little doubt that many of these objects were genuine comets, though not treated as such by the Chinese, a selection of them is inserted in this catalogue, an asterisk (*) being appended either to the year or to M. Biot's name. The remainder are given in a Catalogue of "new stars," in Book VI, *post*[c].

The most recent editor of Chinese comet observations is the late Mr. J. Williams, whose Catalogue published in 1871 is by far the most elaborate work of its sort extant. Great use has been made of this valuable compilation in the revision of the pages which now follow.

It may be well to state that very great uncertainty hangs over the earlier comets, hereinafter referred to, and to some extent, too, over all, more especially as regards the positions in which they were seen and the duration of their visibility.

The Chinese constellations are much more numerous than ours, and where several Greek letters precede a Latin genitive case, it is to be understood that the Chinese place the comet in the group formed of those stars without specifying that it was in juxtaposition with any one star in particular.

[b] 1846, pp. 44–84.

[c] See the Introduction to that Catalogue, for some further remarks on these objects.

The Chinese reckon by moons, and as it rarely happens that the whole of a lunation is comprised in a single Julian month, it is requisite in many cases to couple 2 months together: thus, May—June, which means that the comet appeared in the "moon" which began on (say) May 18, and therefore ended on June 15. In cases where the precise day of the lunation is recorded, the exact Julian day can of course be deduced, and the expedient of coupling together 2 months is superseded. The years B.C. are reckoned in astronomical style.

One *tchang* equals 10°; one *che* equals 1°.

B.C. 1770. ±

[1.] St. Augustine has preserved the following extract from Varro:—"There was seen a wonderful prodigy in the heavens worthy to be compared with the brilliant star Venus, which Plautus and Homer, each in his own language, call the 'Evening Star.' Castor avers that this fine star changed colour, size, figure, and path: that it was never seen before, and has never been seen since. Adrastus of Cyzicus and Dion the Neapolitan refer the appearance of this great prodigy to the reign of Ogyges."—(*De Civitate*, xxi. 8.) This description, such as it is, may be presumed to be that of a comet, but no further particulars have been preserved.

1194. ±

[2.] We are told by Hyginus, a contemporary of Ovid, that "on the fall of Troy, Electra, one of the Pleiads, quitted the company of her 6 sisters, and passed along the heavens toward the Arctic Pole, where she remained visible in tears and with dishevelled hair, to which the name of 'comet' is applied."—(Fréret, *Acad. des Inscriptions*, x. 357.) What we are to understand by this is doubtful, but the account may relate to a comet which passed from Taurus to the North Pole.

975. ±

[3.] "The Egyptians and the Æthiopians felt the dire effects of this comet, to which Typhon, who reigned then, gave his name. It appeared all on fire, and was twisted in the form of a wreath, and had a hideous aspect; it was not so much a star as a knot of fire."—(Pliny, *Hist. Nat.*, ii. 25.) *Date* very uncertain.

619 or 618.

[4.] "We shall see in the W. a star such as is called a comet; it will announce to men war, famine, and the death of several distinguished leaders."—(*Sybill. Orac.* iii.) Though given as a prophecy, Pingré says he feels justified in citing this passage as a historical record. He thinks moreover that the prophet Jeremiah may refer to a comet, and possibly this comet, in *Jer.* i.

611.

[5.] In July a comet appeared among the 7 stars of Ursa Major.—(Confucius, *Tchun-tsieou*, quoted by Ma-tuoan-lin.)

532 or 531.

[6.] At the winter solstice a comet appeared in the Western part of Aquarius, or the tail of Capricornus.—(Gaubil.) Ma-tuoan-lin gives, from Confucius, 531 as the date, and the position σ, α, τ Scorpii. Pingré regards the description as applying to one and the same comet.

524–23.

[7.] In the winter a comet passed from Scorpio to the Milky Way.—(Gaubil; De Mailla, *Histoire Générale de la Chine*, ii. 193.)

515.

[8.] In July a comet was seen near H Herculis. (Williams, 1.)

501.

[9.] In December a comet was seen in the East. (Williams, 1.)

481.

[10.] A comet appeared at the end of the year in the E. part of the heavens. Its length was 2°, and it reached from the star *Yng* (?) to α Scorpii.—(Gaubil; Ma-tuoan-lin; De Mailla, ii. 222.)

479.

[11.] At the time of the battle of Salamis a comet in the shape of a horn was visible.—(Pliny, *Hist. Nat.*, ii. 25.)

465.±

[12.] During a period of 75 days an extraordinary object appeared in the sky, according to the testimony of several writers.—(Damachus; Pliny, *Hist. Nat.*, ii. 58.) A comet may be referred to, but an Aurora Borealis would seem best to reconcile the various European statements. Ma-tuoan-lin speaks of a comet in 466, which Pingré considers identical with the "extraordinary object" of the European writers visible in January or February 465.

432.

[13.] It is certain that a comet appeared in this year.—(Couplet; De Mailla, ii. 244; Ma-tuoan-lin.)

426 *or* 402.

[14.] At the time of the winter solstice, during the archonship of Euclides, at Athens, a comet appeared near the North Pole.—(Aristot., *Meteor.*, i. 6.) There were 2 archons of this name, it is therefore impossible to fix the year of this comet's apparition.

360.

[15.] A comet was seen in China and Japan in the W.—(Couplet; De Mailla, ii. 267; Kaempfer, *Histoire du Japon*, ii. La Haie, 1729.)

345 (?).

[16.] A comet in the form of a mane was seen, which was afterwards changed into that of a spear.—(Pliny, *Hist. Nat.*, ii. 25.) Date very uncertain; Pliny gives the double date of the Olympiad and A. U. C., which do not correspond, so one or the other must be wrong. 345 above is from Pingré.

344.

[17.] "On the departure of the expedition of Timoleon from Corinth for Sicily the gods announced his success and future greatness by an extraordinary prodigy. A burning torch appeared in the heavens for an entire night, and went before the fleet to Sicily."—(Diodorus Siculus, *Bibliotheca Historica*, xvi. 11; Plutarch, *Timoleon.*) Pingré remarks that it is easy to see that the comet appeared in the W., and had a considerable N. declination.

340.

[18.] A comet was seen for a few days near the equinoctial circle.—(Aristotle, *Meteor.*, i. 7.)

304.

[19.] A comet was seen in China.—(Ma-tuoan-lin; De Mailla, ii. 306.)

302.

[20.] A comet was seen in China.—(Ma-tuoan-lin; De Mailla, ii. 306.) The Chinese annalist expressly says that there were 2 comets in 2 years.

295.

[21.] A comet was seen in China.—(Ma-tuoan-lin.)

239.

[22.] A comet was seen in China. It came from the E., and passed by the N., and in the 5th moon (May) it was seen during 16 days in the W.—(Ma-tuoan-lin; Williams, 2.)

237.

[23.] In the 9th year of Chi-hoang-ti a star appeared in the horizon. In April it was seen in the W.; it appeared then in the N., to the S. of the 7 stars of Ursa Major, for 80 days.—(Ma-tuoan lin; Williams, 2.)

233.

[24.] In China a comet was seen in January in the E.—(Ma-tuoan-lin.)

232.

[25.] Four comets were seen during 80 days.—(Williams, 3.)

213.

[26.] A brilliant star was seen in China to come from the W.—(Ma-tuoan-lin; De Mailla, ii. 399.) Probably a comet.

203.

[27.] A torch extended from E. to W. for 10 days in Aug.—Sept. It appeared near Arcturus.—(Julius Obsequens, *Prodigiorum Liber*, 8vo. Amstelodami, 1679, supplement by Lycosthenes; Ma-tuoan-lin.)

202.

[28.] A burning torch was seen in the heavens.—(Julius Obsequens, *Prodig.*, suppl.)

171.

[29.] A large comet with a tail was seen in China at the end of the summer.—(Couplet; De Mailla, ii. 554.)

168.

[30.] A torch was seen in the heavens.—(Julius Obsequens, *Prodig.*, suppl.; Livius, *Historia*, xliii. 13.)

166.

[31.] A burning torch was seen in the heavens.—(Julius Obsequens, *Prodig.*, suppl.)

165.

[32.] A torch was seen in the heavens.—(Julius Obsequens, *Prodig.*, suppl.) We are further told that at one place the Sun was seen for several hours in the night, so that if this object was a comet it must have been an extremely brilliant one.

156.

[33.] In October (end of) a comet 10° long appeared in the W. It was visible for 16 days, and traversed Aquarius and Equuleus to the neck of Pegasus.—(Ma-tuoan-lin; De Mailla, ii. 568.)

154 (i).

[34.] A comet came from the S. W. in January.—(Ma-tuoan-lin; De Mailla, ii. 569.)

154 (ii).

[35.] In July a comet appeared in the N. E.—(De Mailla, ii. 569; Williams, 4.)

153.

[36.] In February a tailed star appeared in the W.—(De Mailla, ii. 571; Williams, 4.)

147.

[37.] A comet appeared in May in the N. W., and lasted 2 or 3 weeks. It had the same R: A. as Orion.—(Ma-tuoan-lin; De Mailla, ii. 588.)

146 (i).

[38.] On March 14 a comet 10 cubits long was seen at night in the N. W., probably in Orion. As it passed on it increased but little in size. After 15 days it was no more seen.—(Williams, 4.)

146 (ii).

[39.] "After the death of Demetrius king of Syria, the father of Demetrius and Antiochus, a little before the war in Achaia, there appeared a comet as large as the Sun. Its disc was at first red, and like fire, spreading sufficient light to dissipate the darkness of night; after a little while its size diminished, its brilliancy became weakened, and at length it entirely disappeared."—(Seneca, *Quæst. Nat.*, vii. 15.) It lasted 32 days.—(Julius Obsequens, *Prodigiorum Liber.*) Probably this account relates to the comet seen this year in China, August 6-16, and which passed from the divisions Scorpio and Sagittarius to near ζ Ophiuchi. The size of the Chinese comet steadily decreased day by day.—(Williams, 4.)

146 (iii).

[40.] In October a comet was seen in the N. W.—(Williams, 5.)

137 (i).

[41.] "In the reign of Attalus a comet was seen which, small at first, afterwards became much larger. It reached the equinoctial circle, and equalled in length that part of the heavens which is called the Milky Way."—(Seneca, *Quæst. Nat.*, vii. 15.) It appeared in March—April, in the lower part of Hydra, and passed through Leo—Virgo into the circumpolar regions, arriving at length at the Milky Way.—(Ma-tuoan-lin.)

137 (ii).

[42.] A comet appeared 2 months after the preceding; it passed from θ, ϵ Herculis to α, ϵ, ζ Lyræ.—(Ma-tuoan-lin.)

137 (iii).

In August a comet was seen in the N. E.—(Williams, 5; Ma-tuoan-lin; De Mailla, iii. 9.)

The preceding 3 comets may in reality have been but one and the same; one of them, or else the comet of 134 (*post*), is the comet which appears in the other catalogue under the date of 136. [*Therefore a number is dropped here.*]

136 (ii.)

[43.] In October a comet was seen in the N. E.—(Williams, 5.)

134.

[44.] At the birth of Mithridates a comet appeared and lasted 70 days; the heavens appeared all on fire; the comet occupied the fourth part of the sky, and its brilliancy was superior to that of the Sun; it took 4 hours to rise and 4 to set.—(Justinus, *De Historicis Philippicis*, xxxvii. 2.) There is very great uncertainty about this comet of Mithridates, but Pingré, after weighing Ma-tuoan-lin's account, considers that 134 was certainly the year. He also says that probably it appeared in the W. in the middle of July; before the end of August it would have been lost for a few days in the Sun's rays, when probably the Perihelion Passage took place; it would then have re-appeared with increased brilliancy early in September in the E. (for 30 days?), and so have passed away from the Sun.—(*Comét.* i. 270, 578.) Ma-tuoan-lin (Williams, 6) would have us consider the comet of September 134 to be different from the comet of July 134, but this does not at all follow.

127.

[45.] A burning torch appeared in the heavens.—(Julius Obsequens, *Prodig.* suppl.)

119.

[46.] In the spring in China a comet was seen in the E.—(De Mailla, iii. 46.)

118.

[47.] When Mithridates ascended the throne there appeared during 70 days a comet exactly resembling that which was seen at the birth of that monarch.—(Justinus, *De Historicis Philippicis*, xxxvii. 2.) It came from the N. W. in May.—(Ma-tuoan-lin; Williams, 6.)

109 (i.)

[48.] In June a comet was seen in the feet of Gemini.—(Ma-tuoan-lin; De Mailla, iii. 61.)

109 (ii).

[49.] This comet appeared contemporaneously with the preceding: it was in Ursa Major, near κ, λ, ξ.—(Ma-tuoan-lin; De Mailla, iii. 61.)

108.

[50.] A comet appeared in the region lying between Procyon (α Canis Minoris) and α and β Geminorum.—(Ma-tuoan-lin.) Or in the year 107; place uncertain.—(Williams, 6.)

102.±

[51.] A comet was seen in China near γ Boötis.—(Ma-tuoan-lin.)

93.

[52.] A torch appeared in the heavens.—(Julius Obsequens, *Prodig.*)

91.

[53.] A torch appeared in the heavens.—(Julius Obsequens, *Prodig.*)

86.

[54.] In August a comet was seen in the E.—(De Mailla, iii. 98; Williams, 7: Pliny, *Hist. Nat.*, ii. 25.) Pliny's is merely an incidental notice. He says that comets foretell bloodshed, and gives as an instance the one which appeared during the consulate of Octavius.

83.

[55.] In March a comet was seen in the N.W.—(De Mailla, iii. 101; Williams, 7.)

75.

[56.] "In the consulate of Cn. Octavius and C. Scribonius a spark was seen to fall from a star; it grew larger as it approached the Earth, and became equal in size to the Moon, and gave as much light as the Sun gives during the daytime when the sky is entirely covered. On returning into the heavens it took the form of a *lampas* [torch, one of Pliny's names for a class of comets]."—(Pliny, *Hist. Nat.*, ii. 35.) The above is a rather obscure explanation, but in Pingré's estimation a comet fairly meets it. In May a bright star was seen in the sidereal divisions of β Andromedæ and β Arietis.—(Williams, 7.)

72.

[57.] On May 10, early in the evening, a tailed star appeared to the W. of the sidereal division of α, β, &c. Orionis.—(Williams, 7.)

71.

[58.] On August 20 a comet appeared in the sidereal division of α Crateris.—(Williams, 8.)

69.

[59.] On August 4 a comet appeared in the sidereal division of α Crateris; it passed near the Moon.—(Williams, 8.) Can this and the previous comet be one and the same?

68 (i).

[60.] In January—February a comet was seen in the W.—(Williams, 8.)

62.

[61.] A burning beam stretched from the western horizon to the zenith.—(Julius Obsequens, *Prodig.*) Torches ran from the W. to the middle of the sky.—(Dion Cassius, *Hist. Roman.*, xxxix.) A comet appeared in the E. in the 6th moon.—(De Mailla, iii. 136.) Dion Cassius's allusion is very doubtful; and whatever may really have been the date of the burning beam, it is believed that De Mailla's comet must be referred to 61, his dates invariably being 1 year behind. [But see the next paragraph.]

60.

[62.] In July a comet was seen in the E.—(Williams, 8.) Perhaps this and De Mailla's comet of 62 or 61 are identical.

55.

[63.] A torch appeared which advanced from the S. to the N.—(Dion Cassius, *Hist. Roman.*, xxxix.)

52.

[64.] A torch appeared, which passed from the S. to the E.—(Dion Cassius, *Hist. Roman.*, xl.)

48.

[65.] During the war between Cæsar and Pompey "a comet, that terrible star which upsets the powers of the Earth, shewed its portentous hair."—(Lucanus, *Pharsalia*, i. 529.) In April a long comet was seen near β Cassiopeiæ; passing by ι in that constellation, it became lost in the circumpolar regions.—(De Mailla, iii. 155.) In March an extraordinary star shewed itself about 9° to the N. E. of α, β, γ, η Cassiopeiæ: it was 10° long, and pointed to the W. It passed by ν, ξ, o, π Cassiopeiæ, and went towards the "blue palace" [circle of perpetual apparition at 34° lat. N.]—(Biot.*)

47.*

[66.] In April—May an extraordinary star, as large as a scourge, was seen: it was 4° or so to the E. of μ Sagittarii.—(Biot.)

46.

[67.] In June an extraordinary star was seen in the sidereal division of the Pleiades, 5° E. of ν Persei. Its tail was $\frac{4}{10}$ of a cubit long.—(Biot*; Williams, 9.)

43 (i).

[68.] In May—June a comet was seen in China, whose R. A. was the same as that of Orion.—(De Mailla, iii. 162.) It was in the N. E., and its tail, which was 8 cubits long, and afterwards longer, pointed to the sidereal division of α, β Orionis.—(Williams, 9.)

43 (ii).

[69.] A hairy star was seen for 7 days under the Great Bear during the celebration of the games given by the Emperor Augustus in honour of Venus. It rose at about 5 in the evening, was very brilliant, and was seen in all parts of the Earth. The common people supposed that the star indicated the admission

of the soul of Julius Cæsar into the ranks of the immortal gods.—(Suetonius, *Vita Julii Cæsaris*, lxxxvii.) It was visible therefore from Sept. 23 to Sept. 29. Dion Cassius says, that, in addition to the comet, which appeared contemporaneously with the Emperor's games, there was seen a burning torch, which traversed the heavens from E. to W.; and also an unknown star, which shone for many days.—(*Hist. Roman.* xlv. 17.) Pingré thinks that the "torch" was simply a meteor, but that the "unknown star" was the preceding object which was seen in China, and there recorded as a comet.—(*Comét.* i. 278.)

42 *and* 41.

[70.] Previous to the battle of Philippi comets appeared.—(Virgil, *Georgica*, i. 488; Manilius, *Astronomicon*, i. 907.) Perhaps a comet in each year.

31.

[71.] A torch appeared for several days.—(Dion Cassius, *Hist. Roman.*, l.) In February a comet 60 or 70 cubits (? degrees) long was seen in the sidereal division of α Pegasi.—(De Mailla, iii. 178; Ma-tuoan-lin; Williams, 9.)

29.

[72.] Before Egypt submitted to Augustus there appeared comets.—(Dion Cassius, *Hist. Roman.*, li.) Lubienitz says that a comet appeared for 95 days in Libra, but he gives no authority.

4.

[73.] In March a comet appeared for 70 days in the sidereal division of α, β, &c. Capricorni.—(De Mailla, iii. 214; Williams, 10.)

3 B.C.

[74.] In April or May a comet appeared near α and β Aquilæ.—(De Mailla, iii. 214; Williams, 10.)

10 A.D.

[75.] Several comets visible at the same time.—(Dion Cassius, *Hist. Roman.*, lvi. 24.) Some modern cometographers state that a comet appeared in Aries for 32 days.—(Lubienitz.)

14.

[76.] Hairy stars of the colour of blood.—(Dion Cassius, *Hist. Roman.*, lvi. 29.) A comet was seen in China for 20 days, either at the end of 13 or the beginning of 14.—(De Mailla, iii. 240; Williams, 10.)

19.

[77.] A comet was seen in China.—(Couplet.)

22.

[78.] In November—December a comet was seen for 5 days. It was in the sidereal division of κ, λ Hydræ, and moved in a S.E. direction.—(De Mailla, iii. 251; Ma-tuoan-lin; Williams, 11.)

39.

[79.] On March 13 a comet became visible in the Pleiades; it moved in a N.W. direction towards α, β and λ, μ Pegasi, and remained in sight for 40 days.—(De Mailla, iii. 326; Ma-tuoan-lin; Williams, 11.)

54.

[80.] In the autumn (?) a comet appeared for a long time. It was first seen in the N.; it moved to the zenith, and thence Eastwards, and day by day diminished in brilliancy.—Dion Cassius, *Hist. Roman.*, lx. 35; Suetonius, *Vita Claudii.*) It appeared in the circumpolar regions.—(De Mailla, iii. 345.) Probably De Mailla's reference is to the next comet.

55 (i).

[81.] On June 4 a comet appeared; the planet Mercury was about 20° in the E. part of the sidereal division γ, ϵ, &c. Geminorum. The comet pointed to the S.E., was bright, and 10 cubits long. It went to the N.E. passing above the W. boundary of the circle of perpetual apparition. It lasted 31 days.—(Williams, 11.)

55 (ii).

[82.] In November a comet appeared which remained visible for 16 weeks, or till March 56. When first seen it was 2° long, and was then moving towards the S.W. It disappeared on March 26, 6° N.E. of γ, δ, η, θ Cancri.—(Gaubil; Biot.*)

60.

[83.] On Aug. 9 a comet, with a tail 2 cubits long, appeared to the N. of η, γ, α, δ Persei. It remained visible for 19 weeks or more, and, passing Southward, disappeared S. of the feet of Virgo.—(Tacitus, *Annales*, xiv. 22; De Mailla, iii. 352; Ma-tuoan-lin; Williams, 11.)

61.

[84.] On Sept. 27 a strange star was detected to the N.W. of ρ, δ Boötis, with a tail pointing towards Corona Borealis. After 17 days it quitted this position, but we are not told whither it went. It was visible for 10 weeks altogether.—(Ma-tuoan-lin; Biot*; Seneca, *Quæst. Nat.*, vii. 28; Williams, 12.) It is uncertain whether the comet seen in China is the same as that spoken of by Seneca.

64 (i).

[85.] On May 3 an extraordinary star, with a vapour 2° long, was seen to the S. of η Virginis; it lasted 11 weeks.—(Gaubil; Biot.*)

64 (ii).

[86.] At the end of the year, in the reign of Nero, a comet appeared for 6 months. It passed from the N. through the W. to the S.—(Seneca, *Quæst. Nat.*, vii. 21, 29; Tac., *Ann.*, xv. 47; Suetonius, *Vita Neronis.*)

65.

[87.] On June 4 a great star was observed in the sidereal divisions of δ and ν Hydræ; it approached near α and γ Leonis, and passing α, γ, δ Persei arrived in the vicinity of β Leonis. The vapour extended to ι and κ Ursæ Majoris; it remained visible 8 weeks.—(Ma-tuoan-lin; Williams, 12.)

69.

[88.] Sometime between April and December a comet appeared.—(Dion Cassius, *Hist. Roman.*, lxv. 8.) Possibly this may be the object referred to by Josephus as having been seen suspended over Jerusalem before its destruction by Titus.—(*Bella Judæorum*, vi. 5.)

70.

[89.] In December 70 or January 71 a strange star appeared in α, γ, ε, η, ζ Leonis for 7 weeks.—(Gaubil; Biot.*)

71.

[90.] On March 6 a comet appeared in the sidereal division of the Pleiades; after 8 weeks it was seen near α, γ, &c. Leonis, and disappeared to the right of the sidereal division of α Virginis.—(Gaubil; Biot*; Williams, 12.)

75.

[91.] On July 14 a comet was discovered in the sidereal division of α Hydræ; its tail was 3 cubits long. Moving to the S. of Coma Berenicis it passed to the vicinity of β Leonis.—(De Mailla, iii. 375; Williams, 13.)

76.

[92.] On August 9 a comet, with a tail 2 or 3 cubits long, was seen between α Herculis and α Ophiuchi, whence it passed to the sidereal division of α and β Capricorni. It remained visible for 6 weeks, and travelled slowly.—(De Mailla, iii. 376; Ma-tuoan-lin; Pliny, *Hist. Nat.*, ii. 25; Williams, 13.)

77.

[93.] On Jan. 23 a comet, with a tail 8 or 9 cubits long, appeared in the R. A. of Aries, whence it moved towards the tail of Draco and the N. Pole. It remained visible for 15 weeks.—(Ma-tuoan-lin; Gaubil; Williams, 13.)

79.

[94.] In the spring (?) a comet was visible for a long time during the illness of Vespasian.—(Dion Cassius, *Hist. Roman.*, lxvi. 17; Suetonius, *Vita Vespasiani.*)

84.

[95.] On May 25 an extraordinary star, 3 cubits long, appeared in the morning in the Eastern heavens. It was in the 8th degree of the sidereal division of μ^2 Scorpii. It traversed ν, ξ, ο, π Cassiopeiæ into the circle of perpetual apparition, remaining visible for 6 weeks.—(Biot*; Williams, 13.) Williams places the comet in the 8th degree of the division of α Muscæ. These 2 divisions are in the original Chinese represented by words of nearly identical sound: hence the uncertainty.

102.

[96.] On the evening of Jan. 7, a greenish white vapour, 30 cubits long, was seen. It extended from ι, κ, χ, φ Eridani towards β Canis Majoris, and was visible for 10 days.—(Williams, 13.)

104.*

[97.] On June 10 a new star appeared in the circumpolar regions; it passed to the Pleiades, and vanished in the next moon.—(Biot.)

108.*

[98.] On July 25 an extraordinary star appeared in Ursa Major, with a tail 2° long, which extended in a S.W. direction towards κ and ι of that constellation.—(Biot.)

110.

[99.] In January a comet rose to the S.W. of γ, δ, ε and ζ Eridani. It had a bluish tail, 6 or 7 cubits long, pointing to the N.E., in which direction (?) it moved. —(Ma-tuoan-lin; Williams, 14.)

115.

[100.] On Nov. 16 an extraordinary star appeared in the W. On the 21st it was to the S. of β and α Aquarii, and afterwards moved to Musca and the Pleiades.—(Biot.*) Gaubil erroneously refers this comet to 117.—(Hind, *Companion to the Almanac*, 1859, p. 12.) Pingré, following Gaubil, reads "β Aquarii and α Equulei."

132.

[101.] On January 29 a strange star, with a tail 2° long, pointing towards the S.W., was observed. Its R.A. was 6° greater than that of β Capricorni; it was also seen near δ, λ, φ Sagittarii, and moved near β Aquarii, α Equulei, and α Aquarii, towards ε and θ Pegasi.—(Ma-tuoan-lin; Biot*; Williams, 14.) This comet was seen in Europe in the time of Adrian, whose courtiers told him that the soul of Antinoüs had been changed into a new star.—(Dion Cassius, *Hist. Roman.*, lxix.) Williams's date is 131 (no month), and his places less precise.

133.*

[102.] On February 8 an extraordinary star, with a vapour 50° long and 2° broad, was seen to the S.W. of γ, δ, ε, &c. Eridani.—(Biot.)

149.

[103.] On Oct. 19 a comet, with a tail 5 cubits long, was observed in the head of Hercules; it was only seen for 3 days.—(De Mailla, iii. 441; Williams, 15.) Gaubil dates its appearance for 148, and Ma-tuoan-lin for 147, but it can be shown by an extraneous circumstance that 149 was really the year.

161 (i).

[104.] In February—March a comet was seen near α Scorpii.—(De Mailla, iii. 459.)

161 (ii).

[105.] On June 14 an extraordinary star appeared in the sidereal division of α Pegasi. It remained nearly stationary for some time, and then retrograded; and when it reached the R.A. of $14\frac{1}{2}^h$ it threw out a tail 5 cubits long.—(Ma-tuoan-lin; Williams, 15.)

180 (i).

[106.] In Aug.—Sept. a comet was discovered near ι, κ, λ, μ, ν, ξ Ursæ Majoris. It moved E. to the tail of Leo, and lasted 3 weeks.—(Ma-tuoan-lin.)

180 (ii).

[107.] A comet was visible in the winter of 180–1 for 2 or 3 months. It came from the E. of Sirius, and moved towards κ, υ, λ Hydræ, where it vanished.—(De Mailla, iii. 506; Ma-tuoan-lin; Williams, 16.)

182 (i).

[108.] In February, March, or April, a comet was seen near δ Andromedæ. It tended towards the E., and entered the circle of perpetual apparition, but left it again after 3 days. It was visible for nearly 9 weeks.—(Ma-tuoan-lin.)

182 (ii).

[109.] In August—September a comet appeared near ι and κ Ursæ Majoris, which was also seen in the vicinity of β Leonis.—(De Mailla, iii. 507; Ma-tuoan-lin; Williams, 16.)

188 (i).

[110.] In March—April a comet was observed in the sidereal division of β Andromedæ. It went the contrary way and became circumpolar, and lasted about 8 weeks.—(De Mailla, iii. 520; Williams, 17.)

188 (ii).

[111.] On July 29 an extraordinary star appeared in Corona Borealis; it moved to the S.W. to α Herculis and α Ophiuchi. It disappeared in the division of μ^2 Scorpii.—(Williams, 17.) Biot dates this comet for June 30, 182.

190. ±

[112.] During the reign of Commodus a hairy star was seen.—(Ælius Lampridius; Herodianus, *Historia*, i.) No more exact date can be assigned.

192.

[113.] In September—October (or October—November) a grand comet 100 cubits long was seen to the S. of the sidereal divisions of α and κ Virginis.—(Ma-tuoan-lin; Williams, 17.)

193.

[114.] In November—December a comet was seen near α and ζ Virginis, moving towards the N. E. On arriving in the region near α Herculis and α Ophiuchi it disappeared.—(Ma-tuoan-lin; Williams, 18.) Another authority places it near α Herculis, &c. at its discovery.—(De Mailla, iii. 363.)

200.

[115.] On Nov. 7 a comet was observed near δ Serpentis.—(De Mailla, iv. 35; Ma-tuoan-lin; Williams, 18.)

204.

[116.] In November—December a comet appeared in the sidereal division of μ Geminorum, which passed by θ, γ, δ Cancri, α, γ Leonis, to the region lying around β Leonis.—(De Mailla, iv. 40; Ma-tuoan-lin; Dion Cassius, *Hist. Roman.*, lxxv. 16; Williams, 18.)

206.

[117.] In February a comet was observed in the square of Ursa Major: the tail extended over the whole of the circle of perpetual apparition: it reached to Ursa Minor.—(De Mailla, iv. 43; Ma-tuoan-lin; Williams, 18.)

207.

[118.] On Nov. 10 a comet appeared in the sign of Leo (or Virgo).—(Ma-tuoan-lin; Couplet; Williams, 18.) De Mailla assigns this comet to the previous year.—(*Hist. Gén.*, iv. 45.)

213.

[119.] In January—February a comet appeared near θ, υ, ϕ Geminorum.—(De Mailla, iv. 63; Williams, 19.)

222.

[120.] On Nov. 4 a new star was observed between β Virginis and σ Leonis.—(Gaubil.) It is uncertain whether this was a comet or a temporary star. Either will accord with the description. Between η and γ Virginis.—(Biot*; Williams, 20.)

225.

[121.] On Dec. 9 a comet was discovered near *m* Leonis; it passed by α, γ Leonis.—(Ma-tuoan-lin; Williams, 20.)

232.

[122.] On Dec. 4 a comet was seen near σ Leonis. It approached β Leonis.—(Ma-tuoan-lin.) Near γ Virginis.—(Williams, 20.)

236 (i).

[123.] On Nov. 30 a comet, with a tail 3 cubits long, was seen near α Scorpii; on Dec. 1 it (or another comet) was seen in the E.—(Ma-tuoan-lin; Gaubil; Williams, 20.)

236 (ii).

[124.] On Dec. 15 a comet was seen; it approached *e*, *f* Ophiuchi and θ, ζ Herculis.—(Ma-tuoan-lin; Gaubil.) Williams treats this comet and the preceding as one, and it appears probable that such was the case.

238 (i).

[125.] In September a comet, with a tail 3 cubits long, was discovered in the sidereal division of κ, λ Hydræ; it moved eastwards (?), and disappeared in 6 weeks.—(Gaubil; Ma-tuoan-lin; Williams, 21.)

238 (ii).

[126.] An extraordinary star was visible from Nov. 29 to Dec. 15. On the former day it was between π Cygni, κ Andromedæ, and λ, μ (or τ, υ) Pegasi. On Dec. 10 it passed near *h*, *g* Tauri Poniatowskii and γ Ophiuchi.—(Gaubil; Biot*; Williams, 21.)

245.

[127.] On Sept. 18 a comet, with a tail 2 cubits long, appeared in the sidereal division of α Hydræ; it moved towards the division of υ Hydræ; it was visible for 3 weeks.—(Gaubil; Ma-tuoan-lin; Williams, 21.)

247.

[128.] On Jan. 16 a comet, with a tail 1 cubit long, was observed: it had the same R. A. as Corvus, and was visible for 56 days.—(Ma-tuoan-lin.) One authority states that the comet was visible for 156 days.—(Williams, 22.)

248 (i).

[129.] In April—May a comet was seen in the Pleiades. Its tail was 6 cubits long, and extended towards the S. W.—(Ma-tuoan-lin.)

248 (ii).

[130.] In August a comet appeared in the sidereal division of α Crateris; it moved towards that of γ Corvi. The tail was 2° long, and the comet remained visible for 6 weeks.—(Ma-tuoan-lin.) Williams (p. 22) treats the two preceding comets as one.

251.

[131.] On Dec. 21 a comet appeared in the sidereal division of α and β Pegasi. It moved westwards, and disappeared after 13 weeks.—(Ma-tuoan-lin; Williams, 22.)

252.

[132.] On March 25 a comet was observed in the sidereal division of Musca, with a tail 50 or 60 cubits stretching towards the S. in the direction of the cross of Orion (δ, ϵ, &c.). The comet was seen for 3 weeks.—(Gaubil; Ma-tuoan-lin; Williams, 22.)

253.

[133.] In December a comet appeared near η Virginis, γ, δ, ϵ Corvi, and afterwards near β Leonis. The tail pointed to the S. W., and was 50 cubits long. It remained visible for 6 months.—(Ma-tuoan-lin; Williams, 22.) Hind remarks that probably the comet's motion was retrograde, and that therefore it receded from the Sun's place towards the W.; also that its path was no doubt more extensive than Ma-tuoan-lin has set down.—(*Companion to the Almanac*, 1859, p. 19.)

254.

[134.] In December a vapour emerged from near δ Sagittarii. Its length is stated to have been very great.—(Ma-tuoan-lin.) Pingré seems to doubt whether this was a comet or not.

255.

[135.] In January—February a comet was seen near ϵ, ζ Aquilæ, to the N. W., near the horizon.—(Ma-tuoan-lin; Williams, 23.)

257.

[136.] In November or December a white comet was seen in the sidereal division of α Virginis.—(Ma-tuoan-lin; Williams, 23.)

259.

[137.] On November 23 a strange star was seen near β Leonis. It moved towards the S. E., traversed the division of γ Corvi, and disappeared in a week.—(Biot*; Williams, 23.)

262.

[138.] On Dec. 2 a comet, with a tail 50° long, appeared in the sidereal division of κ, ι Virginis. It moved towards the N., and was visible for 6 weeks.—(Gaubil.) Ma-tuoan-lin says that its tail was only 5 tsun ($\frac{5}{10}$ of a cubit) long.—(Williams, 23.)

265.

[139.] In June a comet was seen near α, β, η Cassiopeiæ. Its tail was 10 cubits long, and pointed to the S. E., and after 12 days it disappeared.—(Ma-tuoan-lin; Williams, 23.)

268.

[140.] On Feb. 18 a comet was seen in the sidereal division of β Corvi. It advanced to the N.W., and subsequently turned towards the E. (Ma-tuoan-lin; Williams, 24); which remark probably has reference only to the tail.—(Hind.)

269.

[141.] In October—November a comet was seen within the circle of perpetual apparition.—(De Mailla, iv. 148.)

275.

[142.] In January—February a comet was discovered in the sidereal division of β Corvi.—(Ma-tuoan-lin; Williams, 24.)

276.

[143.] A comet was visible from June 23 to September. It moved from the sidereal division of α Libræ, by α Boötis to β Leonis, and passing through the sidereal division of α Crateris, attained to the square of Ursa Major and ι, κ, λ, μ Ursæ Majoris.—(Ma-tuoan-lin; Williams, 24.) Hind suggests that the Chinese account may fairly be considered as applying to the motion of the head (which was therefore retrograde) and the direction of the tail of *one* comet, though Ma-tuoan-lin states that there were *three*. "If Ma-tuoan-lin had been more precise in his dates, we might have approximated to the elements of the real orbit."—(*Companion to the Almanac*, 1859, p. 20.)

277 (i).

[144.] Ma-tuoan-lin (Williams, 24) says that in January—February there was a comet in the W., and in April—May another in the sidereal division of Musca, which two are probably identical.—(Hind, *Companion to the Almanac*, 1859, p. 20.)

277 (ii).

[145.] Ma-tuoan-lin (Williams, 24) states that in May—June there was a comet near π Leonis, and another in June—July in the E.; whilst De Mailla (iv. 162) speaks of a third within the circle of perpetual apparition in August—September. Hind thinks that these three may easily have been but one.—(*Companion to the Almanac*, 1859, p. 20.) Pingré points out that the New Moon fell nearly at the time of the equinox, a circumstance which may have produced an error of one month in the Chinese dates.

278.

[146.] In May—June a very large comet appeared in Gemini. It lasted till the end of the year, or for 8 months (?).—(Ma-tuoan-lin; Gaubil.)

279.

[147.] In April a comet was seen in the sidereal division of δ, ϵ Hydræ; in May another (? the same) near π Leonis. In July—August it was within the circle of perpetual apparition.—(Ma-tuoan-lin; Williams, 25.)

281 (i).

[148.] In September a comet appeared in the sidereal division of κ, υ, λ Hydræ.—(Ma-tuoan-lin; Williams, 25.)

281 (ii).

[149.] In December a comet appeared near γ Leonis.—(Ma-tuoan-lin; Williams, 25.) This might be the same as the preceding, and Hind appears to favour this view of the matter.

283.

[150.] On April 22 a comet was seen in the S. W.—(Ma-tuoan-lin; Williams, 25.)

287.

[151.] In September a comet appeared in the sidereal division of ϕ Sagittarii for 10 days. Its tail was 10 tchang (100 cubits?) long.—(Ma-tuoan-lin; Williams, 25.)

301 (i).

[152.] In January a comet emerged to the W. of β Capricorni, with a tail pointing towards the W.—(Ma-tuoan-lin; Williams, 26.)

301 (ii).

[153.] In April—May a comet was seen near either ω Capricorni or 110 Herculis. —(Ma-tuoan-lin; Pingré.) Near H Herculis.—(Williams, 26.)

302.

[154.] In May—June a comet was visible in the morning.—(Ma-tuoan-lin; Williams, 26.)

303.

[155.] In April a comet was seen in the Eastern heavens, pointing towards ι, κ, λ, μ Ursæ Majoris.—(Ma-tuoan-lin; Williams, 27.)

305 (i).

[156.] In September—October a comet was seen in the sidereal division of the Pleiades.—(Ma-tuoan-lin; Williams, 27.) Under the same date De Mailla places a comet near the Pole.—(*Hist. Gén.*, iv. 248.) This is probably the comet of Ma-tuoan-lin.

305 (ii).

[157.] On Nov. 22 a comet was seen in the square of Ursa Major, near γ of that constellation.—(Ma-tuoan-lin; Williams, 27.) Hind identifies this with the preceding, but not so Pingré.

329.

[158.] In August—September a comet appeared in the N.W. It entered the sidereal division of ϕ, δ Sagittarii, and was visible for 3 weeks.—(Ma-tuoan-lin; Williams, 27.)

336.

[159.] On Feb. 16 in the evening a comet was seen in the W. in the sidereal division of β Andromedæ.—(De Mailla, iv. 349; Williams, 27.) In Europe a comet of extraordinary magnitude was seen for several days a year or more before the

death of Constantine, which happened on May 22, 337.—(Eutropius, *Hi Romana*, x. 8.) Pingré and Hind agree in considering these 2 comets as one, in case possibly it was visible for 2 or 3 months.

340.

[160.] On March 5 or 25 a comet was seen in the vicinity of β Leo (Ma-tuoan-lin; De Mailla, iv. 363; Williams, 28.)

343.

[161.] On Dec. 8 a comet was seen; its R. A. exceeded that of κ Virginis by (Gaubil.) Williams (p. 28) simply says that it was in the sidereal division Virginis, and was 7 cubits long.

349.

[162.] On November 23 a comet, with a tail 10 cubits long, and exte Westwards, was discovered in the sidereal division of κ Virginis. On Feb. 13 it was still visible, and in the same sidereal division.—(Gaubil; Ma-tuoa Williams, 28.)

358.

[163.] On July 1 or 12 a comet was seen in the sidereal division of Musca, γ, η Persei.—(Williams, 28.)

363.

[164.] In August—September a comet appeared in the sidereal divisio α and κ Virginis; it subsequently passed to near α Herculis and α Ophiu (De Mailla, iv. 413; Williams, 28.) During the reign of Jovian, or towar end of the year, comets are said to have been visible in the daytime.—(Amm Marcellinus, *Rerum Gestarum*, xxv.)

373 (i).

[165.] On March 9 a comet appeared. It traversed the following sidereal divi *i. e.* its R. A. successively coincided with the following stars:—ε Aquarii, β Aq α Libræ (April 7), α Virginis, κ Virginis, γ Corvi, α Crateris, and υ Hyd (Ma-tuoan-lin; Williams, 29.) It is not impossible however that the comet tra the above *constellations*, in which case the inclination of its orbit must have very small.

373 (ii).

[166.] On Oct. 24 a comet appeared near α Herculis and α Ophiuchi.— tuoan-lin.) Hind thinks that this was probably *Halley's comet*, which may arrived at perihelion during the first week of November.—(*Companion* *Almanac*, 1859, p. 23.) Williams (p. 29) identifies this comet with the prec which is not a probable theory. For Oct. 24 he gives Sept. 25.

374.

[167.] In January—February a comet was visible in the sidereal division Scorpii and γ Sagittarii.—(De Mailla, iv. 437; Ma-tuoan-lin.) This position also apply to Halley's comet at this epoch, so that it is uncertain whethe comet or the preceding one was that body.—(Hind.) Hind appears to giv preference to the latter. Compare his memoir in *Month. Not.*, vol. x. p. 57. 1850. Williams (p. 29) identifies this comet with 373 (i).

375.

[168.] A few days before the death of Valentinian, which occurred on Nov. 17, comets were observed.—(Ammianus Marcellinus, *Rerum Gestarum*, xxx.)

389.

[169.] In August (probably) a splendid comet appeared. It rose in the N., at the hour of cock-crowing. Resembling the morning star, it burned rather than shone, and ceased to exist in 4 weeks.—(Marcellinus, *Chronicon.*) It appeared in the zodiacal region, but moving apparently on the left of the spectators, and rising and setting with the morning star, it gradually advanced to Ursa Major and Minor. It lasted for about 6 weeks, and vanished near the centre of the former constellation.—(Philostorgius, *Epitome Historiæ Ecclesiasticæ*, x. 9; Nicephoras, *Historia Ecclesiastica*, xii. 37.)

390.

[170.] On Aug. 22 a comet was seen near α and β Geminorum. Passing the vicinity of β Leonis, ι, κ, λ, θ, and ϕ Ursæ Majoris, it entered the "square" of that constellation; on Sept. 17 it arrived within the circle of perpetual apparition: its tail was 100 cubits long.—(Ma-tuoan-lin; Williams, 29.) It lasted 4 weeks.—(Marcellinus, *Chronicon.*) It is certain that 2 large comets appeared in 2 successive years, and, what is equally remarkable, that they both followed nearly the same path from the zodiac to the Pole; the first, seen, or at least recorded, only in Europe; the latter seen both in Europe and China. Marcellinus distinctly records *two* comets. One or other of them is probably the "new star" recorded by Cuspianus.

392.

[171.] A comet appeared.—(Couplet.)

395.

[172.] A great comet appeared in August, which moved from ϵ Sagittarii towards β Aquarii and α Equulei.—(De Mailla, iv. 496.)

400.

[173.] On March 19 a comet, 30° long, appeared in the sidereal division of θ Andromedæ. It rose to ϵ, υ, ξ Cassiopeiæ, and stopped to the W. of the circle of perpetual apparition; it entered the square of Ursa Major, and arrived near ν, ξ, λ, μ, ι, κ. In the next moon (commencing April 11) it passed by β Leonis to β and η Virginis.—(Ma-tuoan-lin; Williams, 30.) Gaubil adds that the comet passed very near χ Ursæ Majoris. The most terrible comet on record. Its form was that of a sword.—(Socrates Scholasticus, *Historia Ecclesiastica*, vi. 6.)

401.

[174.] On January 2 a comet appeared in Corona Borealis and near α Herculis and α, β, ϵ, &c. Cygni.—(De Mailla, iv. 517; Williams, 30.)

402–3.

[175.] In November—December an extraordinary star appeared to the W. of the region lying around β Leonis; two moons later it was nearer that star.—(Biot *; Williams, 31.) "It first appeared in the E. towards that part of the heavens

where Cepheus and Cassiopeia shine. Passing then a little beyond the Great Bear, it overpowered by [the brilliancy of] its wandering hair the beauty of the stars of that constellation, till at length it languished, and finally dissipated itself in a very feeble flame."—(Claudianus, *De Bello Getico,* xxvi. 228 *et seq.*)

415 *or* 416; (i and ii).

[176 and 177.] On June 24 two comets were observed near α Herculis and α Ophiuchi; passing by the former star they were seen in the N. of the sidereal divisions π and σ Scorpii.—(Ma-tuoan-lin; Williams, 31 and 35.) Probably this route applies to only one of the comets. From another Chinese Chronicle it appears that on June 18, 416, two comets were visible. It is most unlikely that in 2 consecutive years in the same moon and on the same day of the moon [Chinese reckoning] 2 pairs of comets should have appeared, so (as Pingré suggests) probably there was only 1 pair, one or the other of the 2 historians having accelerated or retarded their appearance by one year.

418 (i).

[178.] On June 24 a comet was discovered in the middle of the square of Ursa Major.—(Ma-tuoan-lin.) "Cette comète diffère necessairement de la suivante." —(Pingré, i. 599.)

418 (ii).

[179.] "On July 19, towards the 8th hour of the day, the Sun was so eclipsed that even the stars were visible. But at the same time that the Sun was thus hid, a light, in the form of a cone, was seen in the sky; some ignorant people called it a comet, but in this light we saw nothing that announced a comet, for it was not terminated by a tail: it resembled the flame of a torch, subsisting by itself without any star for its base. Its movement too was very different from that of a comet. It was first seen to the E. of the equinoxes; after that, having passed through the last star in the Bear's tail [probably η Ursæ Majoris], it continued slowly its journey towards the W. Having thus traversed the heavens, it at length disappeared, having lasted more than 4 months. It first appeared about the middle of the summer, and remained visible until nearly the end of autumn."—(Philostorgius, *Epitome Historiæ Ecclesiasticæ,* xii. 8.)

In China this comet was seen on Sept. 15 in Leo: it rose above δ or σ Leonis, and passed through the square of Ursa Major, the circle of perpetual apparition, and near ι and κ (or λ and μ) Ursæ Majoris. Its tail, short at first, increased to 100 cubits or more.—(Ma-tuoan-lin; Williams, 31.) It was first seen near δ Cygni, and was visible for 11 weeks.—(De Mailla, iv. 590.) Couplet states that it appeared in November—December. If for *appeared* we could read *disappeared,* Couplet's account would harmonise with those of the other observers.

419.

[180.] On Feb. 17 a comet appeared in the W. of the region lying around β Leonis.—(Ma-tuoan-lin; Williams, 31.)

420 *or* 421.

[181.] In May a comet was seen.—(Couplet.) In Europe a wonderful sign appeared in 421.—(Prosperus Tyronus, *Chronicon.*) Was this "sign" the comet of the Chinese?

422 (i).

[182.] In March a star with a long white ray appeared for 10 nights about the time of the cock-crowing.—(*Chronicon Paschale.* Parisiis, 1688.) On March 16 it was in the sidereal divisions of α and β Aquarii.—(Gaubil.) Ma-tuoan-lin dates its appearance for March 21.—(Williams, 32.)

422 (ii).

[183.] On Dec. 17 a comet was seen near α and β Pegasi.—(Ma-tuoan-lin; Williams, 32.)

423 (i).

[184.] On Feb. 13 a comet was seen in the eastern part of the sidereal division of γ Pegasi.—(Ma-tuoan-lin; Williams, 32.) A comet was frequently seen before the death of the emperor Honorius.—(Marcellinus, *Chronicon.*) This event happened in August.

423 (ii).

[185.] On Oct. 15 a comet was seen in the sidereal division of α and β Libræ.—(Ma-tuoan-lin; Williams, 32.) Hind gives the date as Dec. 14.

432.

[186.] A comet was seen near α and γ Leonis; passing in the vicinity of β Leonis, it disappeared near α Boötis.—(Ma-tuoan-lin.) No moon given.

436.

[187.] On June 21 a comet was seen near π Scorpii.—(Gaubil.)

442.

[188.] On Nov. 1 a comet without a tail was seen in the square of Ursa Major. It soon threw out a tail, and passing θ, υ Ursæ Majoris, through Auriga, ρ and π Tauri, came to π Ceti and γ, δ, μ Eridani. It disappeared in winter.—(Ma-tuoan-lin; Biot*; Williams, 32.) It appeared in December, and remained visible for several months.—(Marcellinus, *Chronicon;* Idatius, *Chronicon.*)

449.

[189.] A comet appeared on Nov. 11 in the vicinity of β Leonis.—(Ma-tuoan-lin; Williams, 33.)

467.

[190.] A comet resembling a trumpet was seen for periods of from 10 to 40 days in the evening sky.—(*Chronicon Paschale;* Theophanes, *Chronographia*, p. 99, Parisiis, 1655.)

499.

[191.] A comet appeared previous to the second invasion of Illyria by the Bulgarians.—(Zonaras, *Annales*, ii. 56. Parisiis, 1686.)

501.

[192.] On Feb. 13 a tailed star appeared in the horizon. On March 2 a grand comet was visible.—(Ma-tuoan-lin. Hind, *Companion to the Almanac*, 1860, p. 78.) For March 2 Williams (p. 33) reads April 14. Probably these notes belong to one and the same object.

504.

[193.] A great and brilliant star, with a long ray, appeared about the time of the death of Ambrosius Aurelius.—(Galfredus, *De Origine et gestis Regum Britanniæ*, viii. 4. Heidelbergæ, 1587.) It is just possible that this description may refer to the preceding comet. Hind seems to be of this opinion.

507.

[194.] On Aug. 15 a comet was seen in the N. E.—(Gaubil.)

519.

[195.] A "fearful star," with a tail turned towards the W., was seen this year, possibly between October and December.—(Theophanes, *Chronographia*, p. 142; Malala, *Historia Chronica*, xvii. Venetiis, 1733.)

520.

[196.] On Oct. 7 a comet, bright like fire, was seen in the E. On Nov. 30 it was observed in the morning.—(Gaubil.)

524.

[197.] A star was seen for 26 days and nights "above the gate of the palace."—(Cedrenus, *Compendium Historiarum*, p. 365. Parisiis, 1647.)

530 *or* 531.

[198.] A great comet was observed in Europe and China, but accounts differ as to the year, though probably it was 531. "It was a very large and fearful comet," and was seen in the W. for 3 weeks. Its rays extended to the zenith.—(Theophanes, *Chronographia*, p. 154; Malala, *Historia Chronica*, xviii.) It was observed [? passed] in October from α Boötis to λ, μ Ursæ Majoris.—(De Mailla, v. 299.) Hind thinks that this was *Halley's comet*. If it arrived in perihelion at the beginning of November it would have occupied the positions given by the historians, and, in any case, it must have been near perihelion at this time. It is not impossible that there was a comet in each of the above years, a theory which might perhaps remove some of the discrepancies which exist on the assumption that there was only one.

533.

[199.] On March 1 a great star appeared.—(Ma-tuoan-lin). There are no further particulars, so it is uncertain whether this was a comet or a temporary star (Hind). Williams (p. 33) gives, but with reserve, the date as January 6, 532. He calls the object, however, a tailed star, in which case no doubt it was really a comet.

534.

[200.] A comet appeared in Leo and Virgo; passing ν, ξ Ursæ Majoris, it moved to the square of Pegasus.—(Gaubil.)

556.

[201.] In November a comet, in the form of a lance, extended from E. to W., or from N. to W.—(Malala, *Historia Chronica*, xviii.) Some writers date this for 555.

560.

[202.] On Oct. 4 a comet, with a tail 4 cubits long, pointing towards the S. W., was seen.—(Williams, 34; Gaubil.)

563.

[203.] A comet, like unto a sword, was seen for a whole year [? month].—(Gregorius Turonensis, *Historia Francorum*, iv.)

565 (i).

[204.] On April 21 a comet appeared.—(Ma-tuoan-lin.) Williams (p. 35) thinks that there is some uncertainty about the year.

568 (i).

[205.] On July 20 a very brilliant comet was seen in the sidereal division of μ Geminorum. It moved towards the E., and stopped 8 "feet" [or degrees ?] N. of θ, η Cancri on Aug. 18, and then disappeared.—(Ma-tuoan-lin; Biot; Williams, 36).

575.

[206.] On April 27 a comet was seen near Arcturus (α Boötis).—(Ma-tuoan-lin; Williams, 34.)

581.

[207.] On Jan. 20 a comet appeared in the S. W.—(Ma-tuoan-lin.) Williams (p. 35) dates this comet for Jan. 26, 580.

582.

[208.] In the month of January many prodigies were seen. A comet appeared, situate, as it were, in a sort of opening; it shone in the midst of the darkness, sparkled and spread out its tail. From the comet a ray of surprising magnitude emanated, which appeared like the smoke of a conflagration as viewed at a distance. The comet was visible in the W. from the first hour of the night.—(Idatius, *Chronicon*, vi. 14.)

584.

[209.] A comet, like a column of fire suspended in the air, was observed, and a great star appeared above it.—(*Chronicon Turonense.*)

588.

[210.] On Nov. 22 a comet appeared near β Capricorni.—(Ma-tuoan-lin; Williams, 38.)

591.

[211.] A comet appeared for 1 month.—(Bonfinius, *Rerum Hungaricum*, I. viii. Hanoviæ, 1606.)

595.

†[212.] On Jan. 9 a comet was visible in the sidereal division of β Aquarii. It moved through the sidereal division of α Aquarii and ϵ Pegasi, towards those of β Andromedæ and β Arietis.—(Gaubil; Ma-tuoan-lin; Simocatta, *Historia*, vii. Parisiis, 1647.) Williams (p. 38) dates this comet for Nov. 10, 594.

602.

[213.] A comet, like unto a sword, was seen in this year.—(Theophanes, *Chronographia*, p. 240.)

About 605 (i).

[214.] In April and May a comet was seen.—(Paulus, Diaconus, *De Gestis Longobardorum*, iv. 33.)

About 605 (ii).

[215.] In November and December a comet was seen.—(Paulus, Diaconus, iv. 34.)

607 (i).

[216.] On March 13 a comet was seen in the sidereal division of μ Geminorum, and near υ, ϕ Ursæ Majoris; it passed by κ, τ, θ &c. Persei, α, β, θ, χ Aurigæ, α, β Geminorum, the *vicinity* of β Leonis, and α Herculis, and stopped after 14 weeks. (Ma-tuoan-lin; Williams, 38.) Probably for Ti-tso (α Herculis) we should read, as Hind suggests, Ou-ti-tso (β Leonis); and if we suppose the "υ and ϕ Ursæ Majoris" to allude to the place to which the tail extended, this otherwise inconceivable route will appear more reasonable.

On April 4 a tailed star appeared in the W. horizon. It traversed the sidereal divisions of β Andromedæ, α and β Arietis, and α and κ Virginis, and then disappeared.—(Gaubil; Williams, 39.) The Chinese account refers this to another comet, but Hind thinks "it is more than probable that in the description of these so-called *first* and *second* comets of this year, there is some confusion as regards the order in which a single comet may have passed through these sidereal divisions and constellations; or observations of the direction of the tail may be mixed up (as occasionally happens) with the positions of the head."—(*Companion to the Almanac*, 1860, p. 85.)

607 (ii).

[217.] On Oct. 21 a comet appeared in "the Southern region;" it was seen in the sidereal divisions of α and κ Virginis and, passing in the vicinity of β Leonis, came to α Herculis: it entered most of the sidereal divisions, but not those of α, β, γ, δ Orionis or γ, ϵ, μ Geminorum; in the beginning of the year 608 it disappeared.—(Williams, 39; Ma-tuoan-lin; who declares this comet to be identical with that of the 4th of April.) For α Herculis, Pingré read β Leonis, as above, and thinks the "European comet or comets of 605 the same as the Chinese comet or comets of 607."—(*Comét.* i. 327.) It is very difficult to decide from the Chinese observations of comets in 607 how many comets really appeared in that year—whether there were 2 or 3, or even more than one.

608.

[218.] A comet emerged this year from α, β Aurigæ, and passing υ, ϕ &c. Ursæ Majoris, came to β, δ, π, ρ Scorpii.—(Ma-tuoan-lin.) This is precisely the path which *Halley's comet* follows when its PP. occurs in October, and as that comet was due about this year, Hind thinks this was it.

614.

[219.] A comet appeared for 1 month during the occupation of Jerusalem by Cosroës, king of Persia.—(Lubienitz, *Theatrum Cometicum*, Lugd. Bat. 1681.) Date *very uncertain*.

615.

[220.] In July a comet was seen to the S. E. of h, v, ϕ, θ Ursæ Majoris. It was from 50° to 60° long, and its extremity had an undulatory motion. It moved to the N. W. for some days, and when it had nearly reached the circle of perpetual apparition it retrograded, and then disappeared.—(Gaubil; Ma-tuoan-lin.) The dimensions assigned by the latter are 5 or 6 tsun ($\frac{5}{10}$ or $\frac{6}{10}$ of a cubit?).—(Williams, 39.)

616 (i).

[221.] In July a comet, with a tail 3 or 4 cubits long, was seen near β Leonis; after some days it disappeared.—(Ma-tuoan-lin; Williams, p. 39). Hind assigns this and the next comet to the year 617.

616 (ii).

[222.] In October a comet appeared in the sidereal division of α, β Pegasi.—(Ma-tuoan-lin; Williams, 39.)

622.

[223.] A comet is recorded by several modern cometographers.—(Lubienitz.)

626.

[224.] In March an extremely brilliant star was seen in the W. after sunset.—(*Chronicon Paschale.*) On March 26 it was situated between the sidereal divisions of the Pleiades and Musca. On March 30 it was near ν, ϵ, ξ Persei.—(Gaubil; Williams, 40.)

632.

[225.] In May or June, or a little later, a sign appeared for 4 weeks in the S. It was called a "beam," and extended from S. to N.—(Cedrenus, *Compendium Historiarum*, p. 425. Parisiis, 1647.)

633.

[226.] A comet, in the form of a sword, was seen.—(J. A. Weber, *Discursus Curiosi*, &c. Salisburgi, 1673.)

634.

[227.] On Sept. 22 a comet appeared in the sidereal divisions of β Aquarii and α Aquarii; it passed through the sign Aquarius, and on Oct. 3 was not visible.—(Gaubil; Williams, 40.)

639.

[228.] On April 30 a comet was seen in the sidereal divisions of α Tauri and Pleiades.—(Ma-tuoan-lin; Williams, 40.) One Chinese authority makes the year 638.

641.

[229.] On July 22 a comet was seen in the region near β Leonis; it approached Coma Berenicis, and on Aug. 26 it had disappeared.—(Ma-tuoan-lin.) De Mailla (vi. 93) dates this comet a month earlier, and Gaubil and Williams (p. 40) say it was in the β Leonis region on Aug. 1.

660.

[230.] Some *modern* cometographers state that a comet was visible in Scorpio for 12 days.—(Lubienitz.)

663.

[231.] On Sept. 27 a comet, 2 cubits long, was seen near o, π, ζ Boötis. On Sept. 29 it had disappeared.—(Ma-tuoan-lin.) For Sept. 27 and 29 Williams (p. 41) reads Sept. 29 and Oct. 1.

667.

[232.] On May 24 a comet was seen in the N. E., near β, θ Aurigæ, and β Tauri.—(Gaubil.) On June 12 it had disappeared.—(Ma-tuoan-lin; Williams, 41.)

668.

[233.] In May or June a comet was seen for a few days in Auriga.—(De Mailla, vi. 145.) This is probably identical with the preceding with an error of one year in the date.

673.

[234.] In the first year of Thierri of France a comet was observed.—(*Vita S. Leodegarii.*) Several historians record a fire or extraordinary iris. Pingré suggests that the whole may be reduced to an Aurora Borealis.

674.

[235.] According to some modern writers a great comet appeared.—(Lubienitz.)

676 (i).

[236.] On Jan. 3 a comet, 5 cubits long, was discovered to the S. of the sidereal divisions of α and κ Virginis.—(Ma-tuoan-lin; Williams, 41.)

676 (ii).

[237.] "In the month of August a comet shewed itself in the E. for 3 months, from the time of cock-crowing until morning. Its rays penetrated the heavens; all nations beheld with admiration its rising: at length, returning upon itself, it disappeared."—(Anastas, *Historia Ecclesiastica*, Parisiis, 1649; Paulus, Diaconus, *De Gestis Longobardorum*, v. 31.) On Sept. 4 a comet appeared in the sidereal division of μ Geminorum; it pointed towards α and β Geminorum; it moved towards the N. E. Its tail, at first 3 cubits long, afterwards increased to 30 cubits. It [the *comet*—Pingré; or the *tail*—Hind] reached to λ, μ and θ, ν, ϕ Ursæ Majoris. On Nov. 1 the comet had disappeared.—(Ma-tuoan-lin; Gaubil.) For Sept. 4 and Nov. 1 in this account, Williams (p. 41) reads July 7 and Sept. 3.

681.

[238.] On Oct. 17 a comet, 50° long, was near α Herculis; gradually diminishing in size, it moved towards α, β, γ Aquilæ, and on Nov. 3 it had disappeared.—(Gaubil; Ma-tuoan-lin; Williams, 42.)

683.

[239.] On April 20 a comet was seen to the N. of α, β, θ, &c. Aurigæ, β Tauri. On May 15 it had disappeared.—(Ma-tuoan-lin; Williams, 42.)

684 (i).

[240.] On Sept. 6 a comet, 10° long, was seen in the evening towards the W. On Oct. 9 it had disappeared.—(Gaubil.) Hind remarks that this single account will

tolerably well describe the position which *Halley's comet* must have been in at its return to perihelion in the year 684, so doubtless this was that celebrated body.—(*Companion to the Almanac*, 1860, p. 88.) For Sept. 6 and Oct. 9 Williams (p. 42) reads July 8 and Aug. 10.

684 (ii).

[241.] On Nov. 11 a star, like a half moon, was seen in the W. country.—(Ma-tuoan-lin.) Hind says "in the *north*"—apparently a misprint. For Nov. 11 Pingré and Biot read Oct. 11, and Williams (p. 42) Sept. 12. It seems doubtful whether a comet is referred to.

707.

[242.] On Nov. 16 a comet appeared in the W.; on Dec. 17 it had ceased to be visible.—(Ma-tuoan-lin; Williams, 43.)

708 (i).

[243.] On March 30 a comet appeared between the sidereal divisions of Musca and the Pleiades.—(Ma-tuoan-lin; Williams, 43.)

708 (ii).

[244.] On Sept. 21 a comet appeared within the circle of perpetual apparition.—(Ma-tuoan-lin; Williams, 43.)

710 *or* 711.

[245.] In the 92nd year of the Hegira a comet, endued with a sensible motion, appeared for 11 days.—(Haly, *Liber Ptolemæi Comment.* Venetiis, 1484.) The year 92 of the Hegira commenced on Oct. 29, 710, and ended on Oct. 18, 711.

712.

[246.] In August—September a comet emerged from the W., and passed near β Leonis, &c. and thence to Arcturus.—(De Mailla, vi. 199.) Williams (p. 43) sees a difficulty in assigning any more exact date than "between 710 and 713."

716.

[247.] A comet of terrible aspect, with its tail directed towards the Pole, is said to have been seen this year, but we have only a modern authority for the statement.—(Sabellicus, *Opera Omnia*, Ennead. VIII. lib. vii. Basileæ, 1560.)

729.

[248.] Several writers speak of 2 comets visible for 14 days in the month of January, the one after sunset and the other before sunrise.—(Bede, *Historia Ecclesiastica*, v.; Monachus Herveldensis, *Chronicon Historiæ Germaniæ*.) It is easy to see that a single comet with a R. A. not greatly differing from that of the Sun, but with a high North declination, would be seen after sunset and before sunrise, and thus satisfy the statement of the Chroniclers. Donati's great comet of 1858 was so visible for several weeks in the month of September of that year.

730.

[249.] On Aug. 29 a comet was seen in Auriga: on Sept. 7 it was in the sidereal divisions of α, γ &c. Tauri and the Pleiades.—(Gaubil.) Ma-tuoan-lin implies that the comet of Sept. 7 was not the same as that of Aug. 29. Williams's dates are June 30 and July 9 (p. 43.)

738.

[250.] On April 1 a comet was seen within the circle of perpetual apparition. It traversed the square of Ursa Major, and was observed for 10 days or more, when clouds interfered.—(Ma-tuoan-lin.) Williams (p. 44) dates this comet for 739.

744.

[251.] A great comet was seen in Syria.—(Theophanes, p. 353.)

762.

[252.] A comet was seen in the E. like unto a beam.—(Theophanes, p. 363.)

767.

[253.] On Jan. 12 a comet, 1 cubit long, was seen near α, β, γ, δ Delphini. It passed over ϵ, ι Delphini and was visible for 3 weeks.—(Ma-tuoan-lin; Williams p. 44.) For Jan. 12 Hind reads Jan. 22.

773.

[254.] On Jan. 17 a tailed star was seen in the sidereal division of δ Orionis.—(Ma-tuoan-lin; Williams, 45.)

813.

[255.] "On Aug. 4 a comet was seen which resembled 2 Moons joined together; they separated, and having taken different forms, at length appeared like a man without a head."—(Theophanes, p. 423.) In spite of the strangeness of this description, Pingré considers it to be really that of a comet, and thinks it possible to find an explanation in the comet's peculiar position with regard to the Sun and the Earth.—(*Comét*. i. 338.)

815.

[256.] In April—May a great comet appeared near β Leonis.—(Ma-tuoan-lin; Williams, 45.)

817.

[257.] On Feb. 5, at the second hour of the night, a monstrous comet was seen in Sagittarius.—(*Vita Ludovici Pii* in Bouquet's Collection, vi.) On Feb. 17 a comet was seen in the sidereal division of α, γ Tauri.—(Ma-tuoan-lin; Williams, 45.)

821 (i).

[258.] On Feb. 27 a comet was seen in the sidereal division of α Crateris. On March 7 it was near σ Leonis.—(Ma-tuoan-lin; Williams, 46.)

821 (ii).

[259.] In July a comet, with a tail 10 cubits long, was seen in the sidereal division of the Pleiades. After 10 days it disappeared.—(Ma-tuoan-lin; Williams, 46.)

828.

[260.] On Sept. 3 a comet, with a tail 2 cubits long, was seen near τ, υ, η Boötis.—(Ma-tuoan-lin.) A comet in Libra.—(Georgius Fabricius, *Rerum Germaniæ... Memorabilium*. Lipsiæ, 1609.) Pingré, not then acquainted with Ma-tuoan-lin, threw doubts on the value of the record for Sept. 3. Williams (p. 46) reads July 5.

834.

[261.] On Oct. 9 a comet, with a tail 10° long, was seen near β Leonis. It went Northwards beyond Coma Berenicis. On Sept. 7 it had disappeared.—(Ma-tuoan-lin; Williams, 46.)

837 (ii).

[262.] On Sept. 10 a comet was seen in the sidereal divisions of β and α Aquarii. —(Ma-tuoan-lin; Boethius, *Scotorum Historia*, x.; Williams, 48.)

838 (i).

[263.] On Nov. 11 a comet was seen in the sidereal divisions of β Corvi and θ Cancri. It was 20 cubits long, and the tail gradually pointed to the W.—(Ma-tuoan-lin; Williams, 48.)

838 (ii).

[264.] On Nov. 21 a comet was seen in the E. country, in the sidereal divisions μ^2 Scorpii and γ Sagittarii. It extended in the heavens E. and W. On Dec. 28 it had disappeared.—(Ma-tuoan-lin.) For Dec. 28, Williams (p. 49) reads Dec. 8. Possibly this and the preceding account both relate to the same object.

839 (i).

[265.] On Jan. 1 a comet was seen in Aries.—(*Annales Francorum Fuldenses*, in Bouquet's Collection, vols. vii. and viii.) On Feb. 7 a comet was seen near δ, τ, χ, ψ Aquarii.—(Ma-tuoan-lin; Williams, 49.) Pingré thinks that the latter could not have been the European comet of Jan. 1.—(*Comét.* i. 614.)

839 (ii).

[266.] On March 12 a comet was seen to the N. W. of ν, ϵ, ξ, ζ Persei. On April 14 it had disappeared.—(Ma-tuoan-lin; Williams, 49.)

840 (i).

[267.] On March 20 a comet was seen between the sidereal divisions of α and γ Pegasi. After 3 weeks it disappeared.—(Ma-tuoan-lin; Williams, 49.)

840 (ii).

[268.] On Dec. 3 a comet was seen in the E. country.—(Ma-tuoan-lin; Williams, 49.)

841 (i).

[269.] Before the battle of Fontenay, that is, before June 25, a comet was seen in Sagittarius.—(*Annales Francorum Fuldenses.*) In July—August a comet was seen near δ, τ, χ, ψ Aquarii and between γ Pegasi and the E. of the sidereal division of γ Pegasi.—(Ma-tuoan-lin; Williams, 49.)

841 (ii).

[270.] On Dec. 22 a comet was seen near α Piscis Australis; it passed through the wing of Pegasus into the circle of perpetual apparition. On Feb. 9, 842, it had disappeared.—(Gaubil; Williams, 50.) It was seen in the W. from Jan. 7 till Feb. 13.—(*Chronicon Turonense.*)

852.

[271.] In March—April a comet was seen in the sidereal divisions of λ and δ Orionis.—(Ma-tuoan-lin; Williams, 50.) Williams dates this comet for 851.

855.

[272.] A comet was seen in France for 3 weeks.—(*Chronicon S. Maxentii*; in Bouquet's Collection, vols. vii. and ix.) Perhaps in the month of August.

857.

[273.] On Sept. 22 a comet, with a tail 3 cubits long, was seen in the sidereal division of π Scorpii.—(Ma-tuoan-lin.) Williams (p. 50) dates this comet for Sept. 27, 856.

858.

[274.] At the time of the death of Pope Benedict III a comet appeared in the E.; its tail was turned towards the W.—(Ptolemæus Lucensis, *Historia Ecclesiastica*, xvi. 9, in Muratori's Collection, vol. xi.) Benedict died on April 8.

864.

[275.] On May 1 a comet was seen.—(*Chronicon Floriacense.*) On June 21 a comet was seen in the N. E. through an opening in the clouds for 15 minutes. It was in the sidereal division of β Arietis, and had a tail 3 cubits long.—(Ma-tuoan-lin; Williams, 30.)

866.

[276.] Comets were seen before the death of Bardas.—(Constantinus Porphyrogenitus, *Incerti Continuatoris*, iv. p. 126.) Bardas was killed on April 21.

868.

[277.] About Jan. 29 a comet was seen for 17 days. It was under the tail of the Little Bear and advanced to Triangulum.—(*Annales Francorum Fuldenses.*) It was seen in China in the sidereal divisions of β Arietis and α Muscæ.—(Ma-tuoan-lin; Williams, 51.) This comet is probably identical with Nos. 23 and 241 of the other catalogue, all three objects being apparitions of what is now known as the "November meteor comet." (See *Month. Not.* xxxiii. 48. Nov. 1872.)

869.

[278.] A comet announced the death of Lotharius the Younger.—(Pontanus, *Historia Gelrica*, v. Hardervici-Gelrorum, 1639.) Lotharius died on Aug. 8. In September—October a comet was observed near χ, κ, θ, τ, β, ρ Persei. It went to the N. E.—(Ma-tuoan-lin; Williams, 51.)

873.

[279.] A comet was seen in France for 25 days.—(*Chronicon Andegavense*, in Bouquet's Collection, vol. vii.)

875.

[280.] The death of the emperor Louis II. was announced by a burning star, like a torch, which shewed itself on June 7 in the N. It was seen also from June 6 in the N. E. at the first hour of the night. It was more brilliant than comets usually are, and had a fine tail. This bright comet, with its long tail, was seen morning and evening during the whole of June. (*Breve Chronicon Andreæ*, in Bouquet's Collection, vol. vii.) After harmonising some discrepancies of dates, Pingré says the comet would have appeared on June 3 in Aries; having but little latitude, it would consequently have risen a little after midnight, and would have been seen the same night. The following days, as its longitude diminished and its N. latitude increased, it would have been seen by June 6 or June 7, in the evening, towards the N. E.—(*Comét.* i. 349.)

877.

[281.] "In the second year of the entrance of Charles the Bald into Italy a comet was seen in the month of March in the W., and in the sign Libra. It lasted for 15 days, but was less bright than the preceding one [that of 875]. In the same year the emperor Charles died."—(*Chronicon Novaliciense*, in Muratori's Collection, vol. ii.) Being in Libra, it was in opposition to the Sun, and therefore visible all night, in the evening in the E. and in the morning in the W.—(Pingré, *Comét.*, i. 350.) Ma-tuoan-lin says that it appeared in the 5th moon, or in June—July. (Williams, 51.)

882.

[282.] On Jan. 18, at the 1st hour of the night, a comet, with a prodigiously long tail, was seen.—(*Annales Francorum Fuldenses.*)

885.

[283.] A comet was seen between λ, μ Persei and κ Geminorum.—(Ma-tuoan-lin; Williams, 51.)

886.

[284.] On June 13 a comet was seen in the sidereal divisions of μ^2 Scorpii and γ Sagittarii. It passed α, β, γ Ursæ Majoris, near to θ, π, ζ or η, τ, υ Boötis.—(Ma-tuoan-lin; Williams, 51.)

891.

[285.] On May 12 a comet, with a tail 100 cubits long, appeared near the feet of Ursa Major; it went towards the E. It passed by the vicinity of β Leonis to α Boötis and Serpens, etc. On July 5 it had disappeared.—(Ma-tuoan-lin; Williams, 51; J. Asserius, *Annales.*)

892 (i).

[286.] A comet appeared this year in the tail of Scorpio. It lasted 12 weeks, and was followed by an extreme drought in April and May.—(*Chronicon Andegavense.*)

892 (ii).

[287.] In June a comet, with a tail 2° long, appeared.—(Ma-tuoan-lin.)

892 (iii).

[288.] In November—December a comet appeared in the sidereal divisions of ϕ Sagittarii and β Capricorni.—(Ma-tuoan-lin; Williams, 52.)

892 (iv).

[289.] On Dec. 28 a comet came from the S.W. On Dec. 31, the sky being cloudy, it was not seen.—(Ma-tuoan-lin.)

Possibly i. and ii. are identical, and also iii. and iv.; and in that case there would have been only 2 comets this year.

893.

[290.] After several months of very bad weather the clouds went away, and on May 6 a comet was seen near ι and κ Ursæ Majoris, with a tail 100° long. It went towards the E., entered the region lying around β Leonis, and traversed Boötes, near Arcturus passing into the region around α Herculis. It was visible for 6 weeks, and its length gradually increased to 200° (?). The clouds then hid it.—(Ma-tuoan-lin.) The length is incredible, though Gaubil gives the same. Gaubil's date is 895, but

Pingré is sure that 893 was the year. Williams (p. 52) pronounces in favour of 893, but misquotes Pingré in doing so.

894.

[291.] In February—March a comet was seen. It had the same R. A. as Gemini or Cancer.—(Ma-tuoan-lin; Williams, 52.)

896.*

[292.] In this year there appeared 3 extraordinary stars, one large and two smaller ones. They were between the divisions of β and α Aquarii. They travelled together for 3 days. The little ones disappeared first, and then the large one.—(Biot.)

900.

[293.] About February an extraordinary star appeared near ϵ Herculis, ι Ophiuchi, W. of α Herculis.—(Biot.*) A comet appeared.—(Lubienitz.)

902.

[294.] About February an extraordinary star was seen below some stars in Camelopardus. After a little while it passed to χ Draconis. On March 2 a shooting star touched it. On March 4 it returned to Camelopardus.—(Biot.*) A comet appeared. (Calvisius, *Opus Chronologicum*. Francofurti-ad-Oderam, 1620.)

904.

[295.] At about the time of the birth of the Emperor Constantine Porphyrogenitus a brilliant comet shewed its rays in the E. It lasted 40 days and 40 nights.—(Leo Grammaticus, *Chronographia*, p. 483.) Constantine was baptized on the festival of the Epiphany, or on Jan. 6, 905; so the comet may be dated for November and December 904.

905.

[296.] On May 22 a comet was seen near α, β Geminorum. It traversed Ursa Major from θ, υ, ϕ, τ past λ, μ, towards ν, ξ. The tail was 30 cubits long. On June 12 the comet stretched from α and γ Leonis towards Serpens: on June 13 clouds obscured the sky; and on June 18 the comet had disappeared.—(Ma-tuoan-lin; Williams, 52.) From the European account in the *Chronicon Floriacense* it would rather seem that it was the *head* of the comet which was in Ursa Major, and that the tail reached to the zodiacal region; but the description is altogether very vague. In all such cases the Chinese accounts are generally preferable.

911.

[297.] About June an extraordinary star appeared near α Herculis.—(Biot.*) A comet appeared.—(Ordericus Vitalis, *Historia Ecclesiastica*, vii.) Pingré, perhaps it may *now* be said without reason, refers this account of Ordericus to the next comet.

912.

[298.] A comet appeared for 15 days in the W., like unto a sword.—(Leo Grammaticus, *Chronographia*, p. 487. Parisiis, 1655.) It lasted for 14 days in the N.W. in March.—(Hugo, Monachus Floriacensis, *Chronicon*, in Bouquet's Collection, vol. viii.) On May 13 a comet was seen in the sidereal division of ν Hydræ. On May 15 it was near χ Leonis.—(Ma-tuoan-lin; Williams, 53.) Probably *Halley's comet*, the PP. occurring early in April.—(Hind, *Month. Not.* R.A.S., x. 55. Jan. 1850.)

912 *or* 913.

[299.] A comet was seen in Egypt in the year 300 of the Hegira.—(Haly, *Liber Ptolemæi Comment.*) That year commenced on Aug. 18, 912, and ended on Aug 6, 913.

923.

[300.] In November—December a comet was seen near θ, γ, δ Cancri.—(De Mailla, vii. 210.) Another authority ante-dates this comet 1 month.

928.

[301.] On Dec. 13 a comet was seen in the S.W. Its R.A. was 5° greater than that of β Capricorni. Its tail was 10° long, and pointed to the S.E. After 3 evenings it ceased to be visible.—(Ma-tuoan-lin.) For Dec. 13 Williams (p. 53) reads Oct. 14.

936.

[302.] On Sept. 21 a comet appeared in the sidereal divisions of β and α Aquarii. It was 1° long, and passed near ξ Aquarii and λ, μ Capricorni.—(Ma-tuoan-lin.) For Sept. 21 Williams (p. 54) reads Oct. 28.

939.

[303.] "There was seen in Italy, for 8 successive nights, a comet of surprising grandeur; it threw out rays of extraordinary length."—(Luitprandi Ticinensis, *Rerum ... Gestarum*, V. i.) Possibly July was the month.

941.

[304.] On Sept. 18 or Nov. 17 (it is not possible to say which, though the former day seems the more likely, from the European account) a comet appeared in the W. It swept Serpens and Hercules, and was 10 cubits long.—(Ma-tuoan-lin; Williams, 54.) It was seen in October for 3 weeks.—(*Chronicon S. Florentii*, in Bouquet's Collection, vols. vii. and ix.) Another Chinese account dates this comet for Aug. 7.—(Williams, 64.)

942.

[305.] In October a comet appeared for 3 weeks in the W.: it had a long tail, and advanced gradually Eastwards to the meridian.—(*Chronicon Andegavense.*) Several authorities say that the comet appeared for only 2 weeks, from Oct. 18 to Nov. 1.—(Witichindus, *Annales.* Francofurti, 1621.) All remark that a great mortality amongst oxen occurred in the following year *in consequence* of the comet's apparition [?].

943.

[306.] On Nov. 5 a comet appeared in the E.: its R.A. was greater than that of α Virginis by 9°. Its tail was 1 cubit long, and pointed to the W.—(Ma-tuoan-lin; Williams, 54.) Comets were seen for 14 nights.—(*Annalista Saxo;* in Eccard's *Corpus Historicum*, Lipsiæ, 1723.)

945.

[307.] "Theotilon, Bishop of Tours, set out from Laon to return to his diocese, but was overtaken on the road by the malady of which he died. He had just partaken of the Holy Sacrament, when a luminous sign was seen traversing the sky. This sign was a cubit long. Its brilliancy was such that it gave light in the middle of the night to those who were charged to conduct to Tours the body of the prelate by a journey of

200 miles."—(Frodoardus, *Chronicon.*) Pingré considers that, apart from other testimony, the duration determines this to have been "une veritable comète."—(*Comét.* i. 356.)

956.

[308.] On March 13 a comet was seen in the cross of Orion. Its tail pointed towards the S.W.—(Ma-tuoan-lin; Williams, 54.) It is possible that "March 13" may not accurately represent the original, owing to a doubt attending the Chinese method of computation.

959.

[309.] At the time of the death of the emperor Constantine Porphyrogenitus a gloomy and obscure star appeared for some time.—(Constant. Porph., *Incerti Continuatoris*, p. 289.) Constantine died on Nov. 9. It was seen from Oct. 17 to Nov. 1.—(Tackius, *Cœli anomalon, id est, de Cometis scriptum.* Gissæ-Hassorum, 1653.)

Biot has an extraordinary star in January, and another in February, 962: he assumes these to be one and the same, and both to be identical with No. 13 of the "calculated" comets.

975 (i).

[310.] In April a comet was seen in the E. (Williams, 55.)

975 (ii).

[311.] A bearded comet was visible from August to October—(Cedrenus, *Compendium Historiarum*, p. 683.) It was first seen on Aug. 3 in the sidereal division of δ Hydræ, between 7 and 9 hours of the morning; the tail was 40 cubits long. The comet traversed Cancer and came to the sidereal division of γ Pegasi, and lasted altogether 12 weeks, during which time it passed through 11 sidereal divisions.—(Gaubil.) It became visible on the 5th moon, which terminated on July 11.—(De Mailla, viii. 58.) There is much reason to believe that this comet is identical with the celebrated ones of 1264 and 1556. Presuming the PP. to have taken place at the end of July, the above accounts will all harmonise extremely well.—(Pingré, i. 357.)

981.

[312.] A comet appeared in the autumn.—(Burkhardus, Monachus S. Galli, *Historia*, i, in Goldastus's *Alamannicarum rerum.* Francofurti, 1606.)

983.

[313.] On April 3 an extraordinary star appeared near β Leonis. More precisely, it was between β and η Virginis: it approached ν, ξ, π Virginis, and went to the N.—(Biot.*) A comet appeared.—(Lubienitz, &c.)

985.

[314.] A comet appeared during the pontificate of John XVI.—(Platinæ, *De Vitis Summorum Pontificorum.* Coloniæ, 1540.)

989 (i).

[315.] On Feb. 10 a comet appeared to the N. of α and β Pegasi. It was 1° long, and lasted 14 days.—(Gaubil; *Annalista Saxo.*) Pingré seems to question the value of Gaubil's citation.—(*Comét.* i. 620.) Possibly the chronicle cited above refers to the 2nd comet of this year, the orbit of which has been calculated by Burckhardt.

990 (i).*

[316.] On Feb. 2 an extraordinary star appeared in the division of γ Corvi: it retrograded towards ν, κ, υ, ϕ Hydræ and disappeared, having travelled 40° in 10 weeks. —(Biot.)

990 (ii).

[317.] A star, with a long tail, appeared in the N. After some days it was in the W., and its tail extended to the E.—(Romualdus Salernitanus, *Chronicon*, in Muratori's Collection, vol. vii.) It was seen in August—September in the W.—(Couplet.)

995.

[318.] On Aug. 10 a comet was seen.—(Hepidannus, *Annales*, in Bouquet's Collection, vol. vii; Florentius Vigorniensis, *Chronicon*.)

998.

[319.] On Feb. 23 a comet, 1 cubit long, was seen to the N. of α and β Pegasi. It lasted a fortnight.—(Couplet; De Mailla, viii. 131; Ma-tuoan-lin; Williams, 55.)

1000.

[320.] A comet appeared on Dec. 14 for 9 days. It frightened everybody.—(Iperius, *Chronicon*, xxxiii.) A meteor appeared at the same time, and the majority of writers confound the one with the other. This may be the real explanation of the fact that a slight doubt hangs over the year as to whether it was 999 or 1000. Pingré thinks it was clearly the latter.

1003 (i).

[321.] In February a comet was seen; it disappeared near the Sun, and was only seen for a few days a little before the rising of that body.—(Hepidannus, *Annales*.)

1003 (ii).

[322.] A comet appeared during the pontificate of John XVII.—(*Chronicon Nuremburgense*.) It lasted a long time.—(*Chronicon Stederburgense*.) It was discovered in China on Dec. 23, when it was situated in the sidereal divisions of μ Geminorum and θ Cancri. It approached very near θ, τ, ι, υ, ϕ Geminorum, passed by α, β Aurigæ, β Tauri, to the cross of Orion, and disappeared after 30 days. Its tail was 4 cubits long, and like a vase in shape.—(Ma-tuoan-lin; Williams, 56.) Some European writers refer to a comet in 1004, which is probably this one prolonged. Pope John was elected on June 13, and lived only till Dec. 7. So can there have been 2 comets between June 1003 and Dec.—Jan. 1003-4?

1005.

[323.] A comet was seen in the S.—(Alpertius, *De Diversitate Temporum*; in Eccard's Collection, vol. i.) It was in the W. in September, at the commencement of the night, and lasted 3 months. It shone with great brilliancy, and did not set till cock-crowing.—(Glaber Rudolphus, *Annales*, in Duchesne's Collection, vol. iv.) It was seen in China in September—October, within the circle of perpetual apparition. —(De Mailla, viii. 158.) On Oct. 4 an extraordinary star appeared in the circumpolar regions near β, γ Draconis: it passed by some little stars between ψ Draconis and δ Ursæ Minoris to some little stars in Camelopardus, N. of Cassiopeia. It only lasted 11 days.—(Biot.*)

1012.

[324.] A comet of extraordinary grandeur was seen for 3 months in the Southern part of the heavens.—(Hepidannus, *Annales.*)

1015.

[325.] A comet was seen in February.—(Protospatas, *Breve Chronicon*, in Muratori's Collection, vol. v.) In China on Feb. 10, 1014, a comet was seen in the W.—(Williams, 64.) Probably one and the same comet, and some error in the year.

1017.

[326.] A comet, like a large beam, was seen for 4 months.—(Sigebertus, *Chronographia*, in Bouquet's Collection, vol. iii; Gerbrandus, *Chronicon Belgicum*, ix. 8.) Hevelius says that it appeared in Leo, but gives no authority for this statement.

1018.

[327.] On Aug. 4 a comet appeared to the N. E. of (it would seem) ζ Ursæ Majoris; it was 3 cubits long, and went northwards. It passed by ω and θ, ν, ϕ Ursæ Majoris, and thence Southwards—(Ma-tuoan-lin; Williams, 56)—by a route which Pingré says must have been erroneously stated. However, it is certain that a comet appeared this year in the Polar regions, and that it lasted about 6 weeks.—(Ditmarus, *Chronicon*, viii.) It is less certain that its length increased to 30°, and that passing Leo it disappeared in Hydra.

An extraordinary star appeared on June 10 to the N.W. of κ Leonis: it advanced rapidly by α Leonis to the vicinity of β Leonis: it touched β Virginis, and passing ι Leonis (or δ Virginis) came to the N.W. of ν, o, ξ, π Virginis. It lasted 11 weeks.—(Biot.*)

1023.

[328.] A comet appeared in Leo during the autumn.—(Ademarus, *Chronicon*, in Bouquet's Collection, vol. x.) The original account contains much that is certainly fictitious.

1024.

[329.] A comet appeared the year before the death of Boleslas I. king of Poland. —(Dlugossus, *Historia Polonica.* Francofurti, 1711.)

1032.

[330.] On July 15 an extraordinary star appeared in the N.E. It approached β Leonis, and threw out a tail. On July 27 it disappeared.—(Biot.*) Cedrenus speaks of a brilliant star having passed from S. to N. this year.—(*Compendium Historiarum*, 730.)

1033.

[331.] A comet, 2° long, appeared on March 5 to "the E. of the N. country" [N. E. ?].—(Ma-tuoan-lin.) It appeared on March 9 about the 10th hour of the night, and lasted till sunrise for 3 nights.—(*Fragmentum Historiæ Francorum*, i. and ii, in Bouquet's Collection, vol. viii.)

1034.

[332.] A column of fire was seen in the E. in September. Its summit inclined towards the S.—(Cedrenus, *Compendium Historiarum*, p. 737.) It appeared between κ, υ, λ, μ, ϕ Hydræ et Crateris.—(De Mailla, viii. 199.)

1035 (i).

[333.] On Sept. 15 a comet appeared in the sidereal divisions of ν Hydræ and α Crateris. It was $7\frac{5}{10}$ cubits long, and lasted 12 days.—(Ma-tuoan-lin; Williams, 56.) Possibly this is identical with the preceding. If 1035 is the right year, probably the column of fire was a meteor.

1035 (ii).

[334.] On Nov. 11 a comet, with a faint tail, appeared near α, β Piscium.—(Ma-tuoan-lin.) For Nov. 11, 1035, Williams (p. 56) reads Jan. 15, 1036.

1041.

[335.] Comets appeared.—(Glycas, *Annales*, p. 316. Parisiis, 1660.)

1042.

[336.] On Oct. 6 a comet appeared. Its motion was from E. to W., and it lasted through the month.—(Glycas, *Annales*, p. 319.)

1046.

[337.] A comet appeared in the 15th year of Henry I. of France.—(Godellus, *Chronica*, in Bouquet's Collection, vol. xi.)

1049.

[338.] On the morning of March 10, before sunrise, a comet was seen near β Aquarii, and α Equulei; it passed by the head of Orion, Musca, and the horns of Aries, and lasted 16 weeks.—(Gaubil.) "La route qu'on assigne a cette comète n'est pas naturelle."—(Pingré, i. 372.) Ma-tuoan-lin is scarcely more intelligible. Pingré is disposed to think that Gaubil has made a mistranslation. The words rendered 'head of Orion' and 'Musca,' united into one word, closely resemble the word standing for 'the circumpolar region.' This affords a certain amount of explanation for the incongruity, and Williams seems to adopt it in saying (p. 56) that the comet passed from the sidereal division of β Aquarii through the circumpolar regions to the sidereal division of β Arietis.

1056.

[339.] In July—August a comet appeared in the circumpolar regions.—(De Mailla, viii. 245.) It seems to have passed southwards to Hydra, but Gaubil places it in the head of Orion when first seen. Ma-tuoan-lin agrees with De Mailla. It was 10 cubits long, and on Sept. 25 had disappeared. [N.B. The head of Orion is *Tsoui*, the other region *Tse-ouey;* pronunciation nearly identical, hence possibly a confusion. See note to No. 338, ante.] Williams's account (p. 57) is simply that a comet was seen within the circle of perpetual apparition, and that it passed through the "seven stars" [of Ursa Major ?].

1058.

[340.] "The death of Casimir, king of Poland, was announced by a comet, which appeared for several nights." (Hennenfeld, *Annales Silesiæ.*) It lasted the whole of Easter week.—(Morigia, *Chronicon*, i, in Muratori's Collection, vol. xii.)

1060.

[341.] Shortly after the death of Henry, king of France, a comet with a long tail appeared in the morning.—(Wilhelmus Malmesburiensis, *De Gestis Regum Angliæ.*) Henry died on Aug. 29.

1067.

[342.] A comet appeared at the death of Constantine Ducas.—(*Chronicon Andegavense.*) This event happened in May.

1069.*

[343.] On July 12 an extraordinary star appeared in the sidereal division of γ^2 Sagittarii: on July 23 it traversed γ, δ, ϵ, λ Sagittarii.—(Biot.)

1070.*

[344.] On Dec. 25 an extraordinary star appeared in Aries, below Musca.—(Biot.)

1071–8.

[345.] During the reign of Michael Parapinatius comets frequently appeared.—(Curopalatæ, *Excerpta e Breviario Historico*, p. 856. Parisiis, 1647.)

1075.

[346.] On Nov. 17 a comet, 3° long, appeared in the S. E. in the middle of the sidereal division of γ Corvi. The day following, the tail was bifid and curved. On Nov. 19 its length was 5 cubits; on Nov. 20, 7 cubits, and it pointed towards η Corvi. On Nov. 29 the comet entered the Hyades and disappeared.—(Ma-tuoan-lin; De Mailla, viii. 285.) For "Hyades" Williams (p. 59) reads "the clouds."

1080 (i).

[347.] On Jan. 6 a comet passed over the sidereal division of μ Scorpii.—(Williams, 64.)

1080 (ii).

[348.] On Aug. 10 a comet, 10 cubits long, appeared to the S. of Coma Berenicis; it was curved, and pointed to the S. E. Its R. A. exceeded that of γ Corvi by 8° or 9°. On Aug. 13 it moved towards the N. W. [Pingré does not understand what is meant], and its R. A. exceeded that of α Crateris by 9°. On Aug. 15 it was 3 cubits long, and curved, and penetrated Coma Berenicis. On Aug. 20 the comet passed very near α, γ Leonis. On Aug. 24 it could not be seen.—(Ma-tuoan-lin; Williams, 59.)

1080 (iii).

[349.] On Aug. 27 a comet, which Ma-tuoan-lin regards as the preceding again visible, appeared in the middle of the sidereal division of ν Hydræ; it lasted till Sept. 14. Pingré is the authority for distinguishing these comets.—(*Comét.* i. 625.)

1096.

[350.] On Oct. 7 a comet like a sword appeared in the Southern part of the heavens.—(*Annalista Saxo.*)

1097 (ii).

[351.] On Dec. 6 a comet was seen in the W.—(Williams, 64.)

1098.

[352.] On June 3, "the night of the capture of Antioch," a comet shone out with great brilliancy.—(Robertus, *Historia Hierosolymitana*, v.)

1101.

[353.] On Jan. 31 a large comet appeared in the W. after sunset.—(*Monarchiæ Sinicæ Synopsis Chronologica.*)

1106.

[354.] A splendid comet appeared this year. It was first seen on Feb. 4, within 1½ feet of the Sun, between the 3rd and 9th hours of the day. In Palestine it became visible on Feb. 7, and in China 3 days later. On Feb. 7 it was in the sidereal division of β Andromedæ, and it passed through the sidereal divisions of β Arietis, α Muscæ, the Pleiades, and ϵ Tauri. The comet remained visible for 7 or 8 weeks, and had a tail 63° long.—(Matthæus Paris, *Historia Major;* Gaubil; Ma-tuoan-lin; Williams, 60; and many others.) [Williams treats Ma-tuoan-lin's account as pertaining to a meteor, but this is out of the question under the circumstances.]

1109.

[355.] In December a comet appeared near the Milky Way, with a tail pointing towards the S.—(Hemingfort, *Chronica,* i. 33.)

1110.

[356.] On May 29 a comet, with a tail 6 cubits long, was seen in the sidereal division of β Andromedæ and β Arietis. It went Northwards towards the Pole, and then became visible throughout the night, and ultimately disappeared in the R. A. of about 4^h.—(*Chronica Regia S. Pantaleonis;* Ma-tuoan-lin; Williams, 60.)

1113.

[357.] A great comet appeared in May.—(Matthæus Paris, *Historia Major; Mat*thæus Westmonasteriensis, *Flores Historiarum.*)

1114.

[358.] A comet at the end of May. It lasted several nights, and had a long tail. —(Henricus Huntingdoniensis, *Historia; Annales Waverleienses.*)

1115.

[359.] An extraordinary star in April—May, near α, β, γ Leonis. It had a long tail.—(De Mailla, viii. 377; *Annales De Margan...a tempore S. Edwardi Confess.*) Probably a comet, though no mention is made of movement.

1125.

[360.] A comet preceded the death of Uladislas, king of Bohemia.—(Dubravius, *Historia Bojemica,* xi. Hanoviæ, 1602.)

1126 (i).

[361.] In June—July a large comet was seen within the circle of perpetual apparition. It passed from α Herculis towards θ, ϕ Ursa Majoris.—(De Mailla, viii. 443.) These Chinese positions will not harmonise with the statement of the Latin historians (Sicardus, *Chronicon,* in Muratori's Collection, vol. vii), unless we suppose the comet to have been in Ursa Major at the end of July, or even at the beginning of August.—(Pingré, i. 392.) Williams (p. 61) dates this comet for May 20, and thinks the reading α Ursæ Minoris to be preferred to α Herculis.

1126 (ii).

[362.] In the moon beginning on Dec. 15 a great comet was seen in China, near the horizon. (De Mailla, viii. 447; Ma-tuoan-lin; Williams, 61.)

1131.

[363.] In September—October a great star appeared.—(Ma-tuoan-lin; Williams, 61.)

1132 (i).

[364.] On Jan. 5 a comet was seen.—(Ma-tuoan-lin; Williams, 61.)

1132 (ii).

[365.] On Oct. 2 a comet appeared; on Oct. 7 it was in the sidereal division of α Muscæ; on Oct. 27 it had disappeared.—(Ma-tuoan-lin; Florentius Vigorniensis, *Chronicon*—continuation.) Williams (p. 61) makes this comet to have been visible from Aug. 14 to Sept. 3.

1133.

[366.] On Sept. 29 a comet was seen near θ, ν, φ Ursæ Majoris.—(Williams, 65.)

1138.

[367.] In August—September a comet appeared.—(De Mailla, viii. 524; Biot.*)

1142-3.

[368.] In December—January a comet appeared.—(*Monarchiæ Sinicæ Synopsis Chronologica.*)

1145.

[369.] On April 15 a comet appeared.—(*Calendarius Ambrosianæ Bibliothecæ*, in Muratori's Collection, vol. ii.) It is not easy to reconcile the conflicting accounts of its course. In China it was first seen in the E. on April 24; on May 14 it was in the sidereal division of δ Orionis [and must have had a considerable North latitude, or it would not have been visible.—Pingré,] and had a tail, pointing to the N. E., 10° long. On June 4 it was like a star; on June 9 it was stationary between α Hydræ et Crateris, and remained visible till July 14.—(Gaubil.) On April 26 it came from the constellations of the E. country. [These are probably the first 7 of the Chinese zodiac, commencing at α Virginis.—Pingré.] After 50 days it disappeared. On July 13 it reappeared in the cross of Orion, and lasted 15 days.—(Ma-tuoan-lin, who adds that a comet was seen on June 4 [when the above was still visible].) Hind considers the former to be certainly *Halley's comet*, and that it passed PP. on April 29. Possibly Gaubil's 'May 24' and the position assigned thereto is apocryphal. Pingré's note was made before Ma-tuoan-lin's account was in his possession: he professes himself unable to decide. But the comet of July 15 might have been different from the 50-day which disappeared on June 15; in which view of the matter the latter might have been Ma-tuoan-lin's June 4 comet. Williams (p. 62) is very brief.

1146.

[370.] A comet was seen for a long time in the W.—(*Chronica Regia S. Pantaleonis.*)

1147 (i).

[371.] The emperor Conrad set out in May for Palestine; his departure was preceded by a comet.—(*Historia Episcoporum Virdunensium.*) On Feb. 8 a comet, 10° long, appeared in the E. for 15 days.—(Gaubil.) On Jan. 6 (or 11) a comet appeared in the S.W. of the sidereal division of α Aquarii and ϵ, θ Pegasi.—(Ma-tuoan-lin.) This writer says that on Feb. 12 (or 17) another comet appeared in the N.E. in the sidereal division of ϵ Aquarii, and that on March 5 (or 7) it had ceased to be visible. (Williams, 62.)

1147 (ii).

[372.] About Aug. 20 in Japan a comet was seen.—(Kaempfer, *Histoire du Japon*, II. iv.)

1152 *or* 1156.

[373.] Ma-tuoan-lin, the former; Gaubil and the Great Annals of China, the latter. On Aug. 15 a comet was seen in the middle of Gemini; the next day it was like Jupiter, and 2° long. On the day *Kouey-tchéou*, or Aug. 22, 1152, *a* comet passed near θ, τ, ι, υ, ϕ Geminorum.—(Ma-tuoan-lin.) On July 26 a comet, 10° long, was seen in the feet of Gemini. On the day *Kouey-tchéou*, or Aug. 2, 1156, it was near θ Geminorum.—(Gaubil.) Williams (p. 62) renders Ma-tuoan-lin's year as 1151, and some other difficulties occur in his account.

1155.

[374.] On May 5 a comet was seen.—(*Chronicon Monasterii Admontensis.*)

1162.

[375.] On Nov. 13 a great comet appeared in the square of Pegasus: it went towards χ and ψ Aquarii. Its tail was more than 10° long.—(Gaubil.)

1165 (i *and* ii).

[376.] Two comets appeared this year in August before sunrise; the one in the N., the other in the S.—(*Chronica de Mailros.*)

1181.

[377.] In July a comet was seen.—(*Chronica de Mailros.*) It appeared shortly before the death of Pope Alexander III.—(Cavitellius, *Annales Cremonenses.*) This happened on Aug. 30. Gaubil mentions a new star, seen on Aug. 11, under the footstool of Cassiopeia. It disappeared after 156 days. Nothing is said as to its having had any movement. Between Aug. 6, 1181 and Feb. 6, 1182, an extraordinary star was visible. From the division of ζ Andromedæ it passed over some little stars in Camelopardus, N. of the head of Ursa Major.—(Biot.*)

1198.

[378.] In November a comet appeared for 15 days. It announced the death of King Richard I. of England.—(Radulphus Coggeshale, *Chronicon Anglicanum.*) Richard died on April 6, 1199.

1204.

[379.] In the year of the capture of Constantinople by the Latins a great comet appeared.—(Sicardus, *Chronicon.*)

1208.

[380.] A comet appeared.—(*Chronicon Weichenstephenense.*) A brilliant star like a fire appeared after sunset for 2 weeks; the Jews regarded it as a sign of the approach of the Messiah.—(Cæsar Heisterbacensis, *Excerpta Historiarum Memorabilium.*)

1211.

[381.] In May a comet was seen for 18 days in Poland.—(M. Cromerus, *Polonia*, vii. Coloniæ Aggripinæ, 1589.)

1214.

[382.] In March two terrible comets were seen.—(Boethius, *Scotorum Historia*, xiii.) No doubt a single comet with a considerable North declination, which would accord with the statement of one comet preceding and the other following the Sun. One author associates the comet with a solar eclipse which happened in 1215.

1217.

[383.] "In the autumn, after sunset, we saw a beautiful sign; a star which soon sank below the horizon. This star was turned towards the South, pointing a little Westwards. Its position faced the crown of Ariadne."—(Conradus, Abbas Urspergensis, *Chronicon.*) Pingré understands the above expression to mean that the comet's azimuth was as much W. of S. as that of Corona Borealis was W. of N.—(*Comét.* i. 398.)

1222.

[384.] In the months of August and September a fine star of the 1st magnitude, with a large tail, appeared. When first seen it was near the place where the Sun sets in December.—(*Annales Waverleienses*, &c.) It was observed in China between the feet of Virgo, Arcturus, and Coma Berenicis. It disappeared on Oct. 8.—(Gaubil.) On Sept. 25 it came from η Boötis. The tail was 30 cubits long. The comet traversed the sidereal divisions of α, β, &c. Libræ, β, δ, &c. σ, α, &c. Scorpii, and then perished, after remaining in sight for 2 months,—(Ma-tuoan-lin.) With this comet we lose the invaluable guidance of this able Chinaman. For 'Sept. 25' Williams (p. 63) reads 'Sept. 15.'

1223.

[385.] Early in July a comet appeared in the Western heavens in the evening twilight. It was looked upon as the precursor of the death of Philip Augustus, King of France.—(*Chronique de France*, M.S.) Most probably *Halley's comet.*—(Hind.)

1226.

[386.] On Sept. 13 a comet appeared between η, τ, ν Boötis and Coma Berenicis. It pointed towards α Boötis. On Sept. 12 (*sic*) it disappeared.—(Williams, 65.)

1230.

[387.] A comet appeared.—(Dubravius, *Historia Bojemica*, xv.) On Dec. 15 an extraordinary star appeared between Ophiuchus and Serpens, below the stars F and D in the head of Cerberus. On March 30, 1231, it had disappeared.—(Biot.)

1232.

[388.] On Oct. 17 a comet, 10° long, was seen in the sidereal division of α Virginis. On the 12th day of its apparition it was 20° long. On the 16th day it was close to

the Moon. On the 27th day, at the 5th watch, it reappeared in the S.E., and was 40° long; it was finally lost sight of on Nov. 14.—(De Mailla, ix. 173; Gaubil; Williams, 63.) It began to disappear on Dec. 2.—(Biot.) The date Nov. 14 is determined by Pingré, but it seems open to question. It must be added that Biot states that it (the comet) was *not* seen on the "16th day" during the moonshine: he likewise doubts whether the "12th day" (and consequently the other days) means that day of the moon or of the comet's apparition; Pingré says the latter, "sans doute." Another entry by Williams (p. 65) assigns this comet to 1237, Sept. 21, but the preponderance of testimony is in favour of 1232.

1239.

[389.] A comet was seen in February.—(*Monarchiæ Sinicæ Synopsis Chronologica.*) Shortly after the birth of Edward, son of Henry III. of England, at the commencement of 1238, a splendid comet appeared for several days before sunrise.—(Polydorus Virgilius, *Anglica Historica*, xvi.) Edward was certainly born in 1239, so no doubt the Chinese date is the correct one.

1240.

[390.] On Jan. 25 a comet was seen; at the end of that month it was observed in the W. During February it continued to appear in the same quarter of the heavens, its tail pointing to the E.—(Rolandinus, *Chronicon*, v. 1, in Muratori's Collection, vol. viii.) In China, on Jan. 31, a comet was seen near α Pegasi; on Feb. 23 it passed near α and β Cassiopeiæ. On March 31 it began to disappear.—(Biot.)

1250.

[391.] A comet appeared in December, about the time of the death of the Emperor Frederick II.—(*Gesta Trevirensium Archiepiscoporum*, No. 266.)

1254.

[392.] In November a comet appeared. (Petrus Pictaviensis, *Chronica*, M.S.)

1262.

[393.] A comet appeared for several months.—(Crusius, *Annales Suevici*, III. ii. Francofurti, 1595.)

1263.

[394.] In July—August a comet was seen in the E.—(Gassarus, *Annales Augustburgenses.*) Of doubtful authenticity, the writer not being contemporary.

1265.

[395.] A comet appeared at the beginning of autumn and lasted till the end of that season. It was visible from midnight.—(*Chronicon Mellicense*, in Pez's Collection, Lipsiæ, 1721.) It was first seen in September.—(Franciscus Pipinus, *Chronicon*, in Muratori's Collection, vol. ix.) It is just possible that there were 2 comets this year; one visible July—September, the other September—November.

1266.

[396.] In August, before daybreak, a comet was seen near the sign Taurus.—(Gregoras, *Historia Byzantina*. Parisiis, 1702.) A visibility of 3 months may be inferred.

1269.

[397.] In the 20th year of the reign of Alexander, King of Scotland, a very fine comet appeared towards noon [sub meridiem].—(Boethius, *Scotorum Historia*, xiii.) 'Towards the S.' would be a good rendering.—(Pingré, i. 415.) It was observed in the E. in August and September.—(Malvecius, *Chronicon Brixiense*, VIII. lxxviii, in Muratori's Collection, vol. xiv.)

1273.

[398.] On Dec. 5 a new star appeared in the Hyades. It moved through Auriga, past θ, ϕ, υ Ursæ Majoris, ϵ, σ, ρ Boötis to Arcturus, and remained visible 3 weeks. —(Gaubil.)

1274.

[399.] Three days before the death of Thomas Aquinas, a comet appeared.—(Guillelmus De Thoco, *Vita S. Thomæ Aquinatis*, x. 60.)

1277.

[400.] On March 9 a comet, 4° long, was seen in the N. E.—(Gaubil; Williams, 66.)

1285.

[401.] In this year a great comet appeared; its tail pointed towards the N.W.—(Ptolomæus Lucensis, *Historia Ecclesiastica*, XXIV. xvii.) On April 5 a very brilliant star was seen.—(Pontanus, *Bohemia Pia*, i. Francofurti, 1608.)

1293 *or* 1294.

[402.] In February 1293 or January 1294 a comet was seen in the circumpolar regions; it passed through the square of Ursa Major.—(Couplet; Gaubil.) On Nov. 7, 1293, a comet appeared as above. It was 1 cubit long, and lasted a moon.—(Biot; Williams, 67.)

1298.

[403.] Celestial signs announced the death of Beomond, Archbishop of Treves [*ob.* Dec. 9, 1299]. In the preceding year a comet was seen, during 12 consecutive nights, at about the 3rd hour of the night. Its head was in the N. and its tail trended Southwards.—(*Gesta Trevirensium Archiepiscoporum.*)

1301 (ii).

[404.] Before Christmas a comet was seen in the W. after sunset. It set before midnight, and lasted 15 days. On Dec. 1 it was in Aquarius and Pisces.—(Ricobaldus, *Compilatio Chronologica.*)

1304.

[405.] On Feb. 3 a comet was seen in the sidereal division of α Pegasi; it passed towards the circumpolar regions, and by the tail of Cygnus and Cepheus; it lasted 11 weeks.—(De Mailla, ix. 483.) Its tail was more than 1 cubit long, and pointed towards the S. E. when discovered; afterwards it pointed towards the N.W. On Feb. 3 it was in the 11th degree of α Pegasi; it subsequently swept π Cygni, χ Andromedæ, and entered the circumpolar regions.—(Biot; Williams, 68.)

1305.

[406.] Three days before and 3 days after Easter, or from April 15 to April 21, a long tail was seen.—(Botho, *Chronica Brunswicenses.*)

1313.

[407.] From April 13 or 20 a comet was seen in the E. part of the sidereal division of μ Geminorum. It remained visible a fortnight.—(Biot; Gaubil; Williams, 68; Mussatus, *Historia Augusta*, xv. 4, in Muratori's Collection, vol. x.)

1314.

[408.] In October [?] a comet appeared in the latter part of [the sign?] Virgo, towards the N.—(Paulus Cygnæus, *Chronicon Citizense.*) The accounts are very vague and contradictory. One writer dates its visibility from May 1, and says that it remained visible for 6 months.—(Pontanus, *Historia Gelrica*, vi.)

1315.

[409.] On Oct. 29 a comet was discovered in the region lying around β Leonis. On Nov. 28 it was in the circumpolar regions. It then traversed 15 sidereal divisions from that of γ Corvi to that of γ Pegasi. It remained in sight till March 11, 1316. —(Gaubil; Biot; Williams, 68.) European writers say that 2 comets were visible from Dec. 1315 to Feb. 1316. The first was much larger than the second.—(Hegecius, *De Stellâ Novâ anni* 1571, *&c.*) The N. P. D. of the larger one, on Dec. 25, at 17^h, was 18° $38'$; on Jan. 15, at 17^h, it was only 9° $49'$.—(Mussatus, *De Gestis Italicorum*, vii. 14, in Muratori's Collection, vol. x.) Those who speak of the second comet say that it appeared in the E.—(*Chronicon Rotomagense.*) Can it be that after all there was only 1 comet?

1334.

[410.] In August a comet, with a tail 7½ feet [degrees?] long, was seen.—(*Monarchiæ Sinicæ Synopsis Chronologica.*)

1337 (ii).

[411.] A comet was seen in Cancer during the visibility of the Great Comet of this year. It lasted 2 months.—(Giovani Villani, *Chroniche*, XI. lxvi, in Muratori's Collection, vol. xiv.) The Great Comet was visible for 3 months or more, from May. Chinese writers seem to speak of 2 comets. The lesser one passed from α, β, η Cassiopeiæ to Corona Borealis, and lasted from May 4 to July 31.

1338.

[412.] On April 15 a comet was discovered; the Sun being then in Taurus, the comet was in Gemini. Its movement was from W. to E. with a N. declination. It followed the Sun, and set about midnight. On April 17 it was in 24° of Gemini. From a note by Friar Giles it appears that its latitude was then 17° or 18° N. It remained in sight a fortnight or more.—(*Chronicon Rotomagense.*)

1340.

[413.] On March 24 a comet was discovered in the 7th degree of the sidereal division π Scorpii. It went slowly to the N.W. "When first seen it was in the latter part of Libra; then it retrograded at the rate of 5° a day, till it came to Leo, where it disappeared." It was visible 32 days.—(De Mailla, ix. 576; Gaubil; Williams, 71; Gregoras, *Historia Byzantina*, XI. vii. 5. Fol. Parisiis, 1702.) Biot's chronicler states that this comet was in shape like a *bale of cotton!*

1345.

[414.] At the end of July a comet appeared near the head of Ursa Major; it advanced day by day to the zodiac, and when it reached the latter part of the sign Leo, where the Sun was, it disappeared.—(Gregoras, *Historia Byzantina*, XV. v. 6.)

1347.

[415.] In the reign of Louis of Bavaria a comet appeared for 2 months. In Italy it was seen during 15 days in August in 16° of Taurus, and the head of Medusa.—(*Chronicon Nuremburgense.*)

1356.

[416.] On Sept. 21 a comet was seen precisely in the E. at 17° in the sidereal division of ν Hydræ; it remained visible till Nov. 4. When discovered it was near α Leonis, and had a tail 1 cubit long which pointed to the S.W.—(Gaubil; Biot; Williams, 71.)

1360.

[417.] A comet was seen in the E. for a few days from March 25.—(*Chronicon Zwetlense*, in Pez's Collection; De Mailla, ix. 633.) For March 26 Williams (p. 71) reads March 12.

1362 (ii).

[418.] On June 29 a comet, with a tail 1 cubit long pointing to the S.E., was seen in the circumpolar regions. Its R.A. was $2\frac{80}{100}$° greater than that of β Capricorni [Biot, $9\frac{80}{100}$°]. It went to the S.W. On July 6 the luminous envelope swept θ Draconis; on Aug. 2 the comet had disappeared, having lasted 5 weeks.—(Gaubil; Williams, 72.) De Mailla says that the comet appeared near α and β Capricorni, and that its tail was more than 100 feet long.—(*Hist. Gén.* ix. 640.) This account is altogether irreconcileable with Gaubil's. Can there have been 3 comets this year, or does not De Mailla rather refer to the first comet, the orbit of which has been calculated, and therefore appears in Catalogue I.?

1363.

[419.] On March 15 a comet appeared in the E. It was visible during the current moon.—(Biot; Williams, 72.)

1368.

[420.] In February, March, and April, a comet appeared in the evening in the W. or N.W. to the N. of the Pleiades.—(Couplet; Walsingham, *Historia Anglica.*) On Feb. 7 a comet was seen in the sidereal divisions of the Pleiades and ε Tauri. On April 7 a comet was seen in the N.W. between τ, κ, ρ and α, γ, η Persei; the tail was 8° long, and pointed towards θ, υ, φ Ursæ Majoris. It ultimately disappeared to the N. of α and β Aurigæ.—(Biot; Williams, 74.)

1371.

[421.] On Jan. 15 a very great comet was seen in the N. Its tail was directed towards the S.—(Bonincontrius, *Annales*, in Muratori's Collection, vol. xii.)

1373.

[422.] In April—May, three [?] comets entered the circle of perpetual apparition. —(Biot.)

1376.

[423.] On June 22 a great comet appeared in Cetus near ι, θ, η; it traversed δ, ϵ, μ, ν Piscium, ν Persei, entered the circle of perpetual apparition, swept θ, v, ϕ Ursæ Majoris, and directing itself towards δ, ϵ, π, ρ Draconis, entered the sidereal division of ν^1 or 39 Hydræ. It disappeared on Aug. 8.—(Biot*; Gaubil; Williams, 87.)

1380.

[424.] On Nov. 10 a comet appeared.—(Cygnæus, *Chronicon Citizense.*)

1382 (i).

[425.] On March 30 a comet appeared.—(Botho, *Chronicon Brunswicense.*)

1382 (ii).

[426.] On Aug. 19 a comet appeared in that part of the heavens where the Sun sets in June. It lasted for 15 days, and was seen 2 hours before sunrise, though these two latter statements may be open to doubt.—(*Annales Vicentini;* in Muratori's Collection, vol. xiii.)

1382 (iii).

[427.] In December a comet appeared in the W. for more than a fortnight.—(Walsingham, *Historia Anglica.*)

1388.

[428.] On March 29 a star appeared in the Eastern part of the sidereal division of γ Pegasi.—(Biot*; Williams, 88.)

1391.

[429.] In May a small comet appeared near the stars of Ursa Major. Its tail was not very bright.—(*Annales Foroliviensen;* in Muratori's Collection, vol. xxii.) Biot says that 2 comets appeared on the 23rd of this month; one entered the circle of perpetual apparition between α and ι Draconis and passed to the S. of θ Draconis, and the other passed by the N. of Camelopardus and swept the Pole-star.—(Williams, 74.)

1399.

[430.] In November a star of extraordinary brilliancy was seen; its tail was turned towards the W.; it lasted only a week.—(F. E. Du Mezerai, *Histoire de France.* Abridged ed., 4to. Paris, 1668.)

1402 (i).

[431.] About Feb. 8 a comet appeared, which afterwards became very brilliant, so much so as to be visible in the daytime. It lasted till the middle of April. It appears to have been in the S.W. when first seen, setting in the W. At the beginning of March it was in Aries, and was seen from $2\frac{1}{2}^h$ before till 3^h after sunset, or even later. Subsequently it was seen in the N.W. On Palm Sunday, March 19, its size was prodigious.—(Walsingham, *Historia Anglica;* Poggius, *Historia Florentina,* in Muratori's Collection, vol. xx; Ebendorfferus, *Chronicon Austriacum,* in Pez's Collection.) The daylight visibility of this comet extended to 8 days, the longest instance of the kind on record.

1402 (ii).

[432.] From June to September an immense comet was visible in the W.—(Ducas, *Historia Byzantina.* Fol. Parisiis, 1649.) The descriptions are long, but contain

nothing of practical value. The comet was visible in the daytime, and *perhaps* it attained its maximum brilliancy at the end of August. This or the preceding was regarded as the sign, by some even the cause, of the death of John Gallius Visconti, Duke of Milan.—(*Annales Forolivienses.*)

1406.

[433.] Sometime between January and June a comet appeared in the W. for several nights.—(*Chronica Bremenses.*)

1407.

[434.] On Dec. 15 a comet was seen.—(Biot; Williams, 75.)

1408.

[435.] On Oct. 16 a comet, or something like one, was seen.—(Antonius Petrus, *Diarium Romanum ;* in Muratori's Collection, vol. xxiv.)

1430 (i).

[436.] A terrible comet appeared on Aug. 24.—(Kaempfer, *Histoire du Japon,* II. v.) On Sept. 9 a great star appeared near α, β Canis Minoris. It lasted 26 days. —(Biot* ; Williams, 88.)

1430 (ii).

[437.] On Nov. 14 an extraordinary star was seen to the S. of δ, ϵ, μ, ν Piscium. It went to the S.E., passed near ι, θ, η Ceti, and disappeared in 8 days.—(Biot*; Williams, 89.)

1431.

[438.] On May 15 or 27 a comet, 5 cubits long, was observed in the Eastern part of the sidereal division of μ Geminorum.—(Gaubil; Biot; Williams, 75.) Is this identical with the "star" seen on Jan. 3 near μ Eridani which lasted 15 days?—(Williams, 89.)

1432.

[439.] On Feb. 2 a comet, about 10° long, appeared in the E. It swept the region near α Cygni, and went to the S.E. On Feb. 12 it began to disappear. On Feb. 29 another comet [doubtless the same after its PP.] became visible for 17 days. —(Biot; Williams, 75.) It lasted 8 days, and its tail pointed from E. to N.—(Michovius, *Chronica Polonorum,* IV. xlvii.) Williams has a doubt whether for Feb. 29 we should not read Oct. 26, in which case there were 2 comets in 1432.

1436.

[440.] James I. of Scotland was assassinated on Feb. 20, 1437. During the previous autumn a comet was seen.—(Boethius, *Historia Scotorum,* xvii.)

1439 (i).

[441.] On March 25 a comet was seen in the sidereal division of ν Hydræ. It went to the W., and swept ξ, ψ, ω Leonis and κ, ξ Cancri. It then went to the N., and passed into the sidereal division of θ Cancri. On April 2 it had a tail 5 cubits long.—(Biot.) Williams (p. 76) makes the tail 50 cubits long.

1439 (ii).

[442.] On July 12 a comet, about 10° long, appeared near the Hyades for 7 weeks. It pointed to the S.W.—(Biot; Williams, 76.) Perhaps the preceding, after its PP.

A comet, lasting 1 month, was seen this year in Poland, between the W. and the S. —(Dlugossus, *Historia Polonica*, xii.) In Japan also a comet was seen.—(Kaempfer, *Histoire du Japon*, II. v.)

1444.

[443.] A comet appeared about the time of the summer solstice: on June 15, according to others.—(G. Fabricius, *Rerum Germaniæ...Memorabilium.*) On Aug. 6 a comet, 10° long, was seen to the E. of β Leonis. It became longer day by day till Aug. 15, when it entered the sidereal division of α Virginis, and disappeared.—(Biot; Williams, 76.)

1452.

[444.] In March—April a comet appeared near the Hyades.—(Gaubil.) On March 5 a comet appeared in the sidereal division of ϵ Tauri.—(Biot; Williams, 77.)

1453.

[445.] On Jan. 4 an extraordinary star appeared near the nebula in Cancer. It went slowly Westwards.—(Biot*; Gaubil; Williams, 89.)

1454.

[446.] In the summer a comet like a sword became visible in the evenings after sunset.—(Phranza, *Chronicon De Rebus Constantinopolitanis*, viii. Fol. Venetiis, 1733.)

1457 (i).

[447.] At the commencement of the year a comet appeared.—(Pontanus, *Historia Gelrica*, ix.) Between Jan. 14 and 23 a comet, ½ cubit and more long, appeared in the sidereal division of ϵ Tauri. It went to the S. E.—(Biot; Williams.)

1457 (ii).

[448.] In June a comet appeared in the 20th degree of Pisces.—(*Chronicon Nuremburgense*, and others.) The conclusion seems unavoidable that there were 2 comets in June, and that this is not identical with the one computed by Hind.

1457 (iv).

[449.] On October 26 a comet ½ cubit long appeared in the sidereal division of α Virginis. It passed near ζ and θ Virginis. (Williams, 78.)

1458.

[450.] On Dec. 24 a star appeared in the sidereal division of α Hydræ; it went to the W. till Dec. 27, when it became faint: it was near α, γ, ζ, η Leonis. On Dec. 31 it had a tail ½ cubit long; it "attacked" λ (or ϕ) Cancri. On Jan. 12, 1459, it disappeared in the Eastern part of the sidereal division of μ Geminorum.—(Biot*; Williams, 89.)

1458 *or* 1459.

[451.] Probably the former. In June—July a comet appeared in Taurus (?).—(De Mailla, x. 236; A. Rockenbackius, *Exempla Cometarum.*)

1460.

[452.] James II, King of Scotland, was killed on Aug. 3, 1460. The evening before, a very brilliant comet with a long tail was seen.—(Boethius, *Historia Scotorum*, xviii.)

1461.

[453.] On July 30 a white star appeared near k, l, g Tauri Poniatowskii. On Aug. 2 it transformed itself into a vapour, and disappeared.—(Biot *.) On Aug. 5, a comet was seen in the E. It pointed to the S.W. It entered the sidereal division of μ Geminorum. On Sept. 2 it began to disappear.—(Williams, 79.) These accounts do not seem reconcileable.

1463.

[454.] In this year (no month assigned) a comet was seen near τ and υ Virginis. —(Gaubil.)

1464.

[455.] In the spring a comet was seen in Leo.—(Gaubil.)

1465.

[456.] In March and April a comet was seen, with a tail 30° long, in the N.W.—(Biot; Williams, 79; Kaempfer, *Histoire du Japon*, II. v.)

1467.

[457.] In October a comet was seen above Pisces, "as if it had been formed in Cancer." Rainy weather prevented its being often seen.—(*Chronicon S. Ægidii Brunswicensis.*) Pingré does not seem to attach much credibility to this account.

1468 (i).

[458.] On Feb. 24 a comet was seen near Ursa Major.—(Gaubil.)

1471.

[459.] In the autumn, in Poland, a very great comet was seen. It rose before sunrise. It was in the latter part of Virgo and in Libra, and lasted a month.—(Michovius, *Chronica Polonorum*, IV. lxii.)

1476.

[460.] From Dec. 1476 to Jan. 5, 1477, a small comet was visible.—(Ripamontius, *Historia Urbis Mediolanensis*, vi.)

1477.

[461.] In December a comet appeared.—(*Chronica Bossiana.*)

1478.

[462.] In September a great comet appeared.—(*Chronica Bossiana.*)

1495.*

[463.] On Jan. 7 a star was seen near θ, ρ Ophiuchi; it travelled with a slow motion till Feb. 20, when it entered the division of α Aquarii.—(Biot.)

1502.*

[464.] On Nov. 28 a star appeared near Pyxis Nautica. From the division of υ^1 Hydræ it directed itself towards that of α Crateris. On Dec. 8 it disappeared.— —(Biot.)

1503.

[465.] At about the time of the Festival of the Assumption of the Virgin Mary [Aug. 15] a comet was seen. Its tail pointed towards the E.—(*Chronicon Waldsassense.*)

1505.

[466.] A comet was seen in Aries. It lasted only a few days.—(Mizaldus, *Cometographia.* 4to. Parisiis, 1549.)

1512.

[467.] In March and April a comet appeared.—(*Chronicon Magdeburgense.*)

1513.

[468.] From Dec. 1513 to Feb. 21, 1514, a comet was visible. It passed from the end of the sign Cancer to the end of that of Virgo, and was seen all night.—(Vicomercatus, *Commentarii in lib. Aristotel. Meteor.*, xlix.)

1516.

[469.] The death of Ferdinand the Catholic, King of Arragon (Jan. 23), was announced by a comet, which lasted many days.—(P. Bizarus, *Historia Genuensis*, xix. 446.) Others say that the comet was only visible for a few days.

1518.

[470.] During the nights preceding April 6 a pale comet was seen above the citadel of Cremona.—(Cavitellius, *Annales Cremonenses.*)

1520.

[471.] In February a comet appeared.—(Biot; Williams, 82.)

1521.

[472.] In April a comet with a short tail appeared in the latter part of Cancer.—(Vicomercatus, *Comment. in Aristot.* xlix; Lubienitz.) Month and position depend only on modern authority. On Feb. 7 a star appeared in the S.E.; it was 6° or 7° long: it went from E. to W., and divided itself.—(Biot.*) Gaubil alludes to this, but his description was supposed by Pingré to belong to Jupiter.

1522.

[473.] A comet was seen in the W.—(Mizaldus, *Cometographia*, II. xi.) No month given.

1523.

[474.] In July a comet was seen near α Ophiuchi.—(Biot; Williams, 82.)

1529.

[475.] In February a long star traversed the sky. This phenomenon renewed itself in August.—(Biot.*) European writers mention a comet in August, but Pingré considers that their descriptions belong to an aurora.—(*Comét.* i. 486.)

1530.

[476.] On Nov. 30 a comet was seen.—(Conradus Urspergensis, *Chronicon.* Fol. Argentorati, 1609.)

1532.

[477.] A comet appeared in the spring—(Gaubil.) On March 9 a star with a tail appeared in the S.E. After 19 days it disappeared.—(Biot*; Williams, 92.)

1534.

[478.] A comet appeared in July.—(Cavitellius, *Annales Cremonenses.*) On June 12 a star was seen near π Cygni, κ Andromedæ, &c.; it passed by θ Andromedæ, and entering ν, ξ, o, π Cassiopeiæ, disappeared after 24 days.—(Biot*; Williams, 92.)

1536.

[479.] On March 24 a star was seen near β, γ Draconis. It went Eastwards, and, passing to the W. of δ, ϵ, π, ζ Draconis, came to the Milky Way, and disappeared on April 27.—(Biot*; Williams, 92.)

1538.

[480.] On Jan. 17 P. Apian saw a comet, with a tail 30° long, in 5° of Pisces, with a latitude of 17° N. On the 22nd Gemma Frisius observed it in 9° of Pisces, with a latitude of 11° N.—(Pingré, *Comét.*, i. 495.)

1539.

[481.] On April 30 a comet, with a tail 3° long, was seen. It remained visible for 3 weeks, and swept α and γ Leonis.—(Biot; Williams, 83.) On May 11 (?) Gemma Frisius observed it in 5° of Leo, with a latitude of 12° N. On May 17, at 10^h in the evening, its position, according to Apian's observations reduced by Pingré, was 20° of Leo, with a latitude of $4\frac{1}{2}$° S.—(Pingré, *Comét.*, i. 500.)

1545.

[482.] A comet was seen for several days. No month is given.—(Aretius, *Brevis Cometarum Explicatio.*) On Dec. 26 a comet appeared near β, γ Draconis; it entered the sidereal division of δ Sagittarii, and returned to the N.E. It disappeared at the end of the Moon.—(Biot*; Williams, 92.)

1554.

[483.] On July 23 a comet was seen, which passed from δ to θ, υ, ϕ Ursæ Majoris, and thence to α Serpentis. It lasted 4 weeks.—(Biot; Williams, 83.)

1557.

[484.] In October, the Sun being in Libra, a comet was seen in the W., in Sagittarius.—(J. Camerarius, *Cometæ.* 8vo. Lipsiæ, 1558.) On Oct. 22 it was seen near λ Ophiuchi; it pointed to the N. E. It lasted till the next moon.—(Biot.) For 'Oct. 22' Williams reads 'Oct. 10,' and for 'N.E.' he reads 'N.W.'

1560.

[485.] In December a comet appeared for a month.—(J. A. Thuanus, *Historiæ sui temporis*, xxvii. 11. Fol. London, 1733.)

1569.

[486.] In November a comet was seen in Ophiuchus and in the signs Sagittarius and Capricornus. Its movement in longitude equalled the extent of these 2 signs, and it remained visible till Nov. 19.—(Kepler, *De Cometis*, 114.) It lasted from Nov. 9 to Nov. 28.—(Biot; Williams, 84.)

1578.

[487.] On Feb. 22 a star as large as the Sun appeared.—(Biot*; Williams, 92.) European writers mention a comet and a hairy star, the latter on April 1. As Tycho Brahe's comet of 1577 remained visible till January 1578, Pingré thinks that that is the object described as the comet of 1578: the hairy star of April he considers to have been a meteor.

1591.

[488.] On April 3 a comet, 1 cubit long, was seen. It traversed the sidereal divisions of α Aquarii, α Pegasi, and γ Pegasi, increasing in length to 2°. On April 13 it entered the sidereal division of β Arietis.—(Biot; Williams, 85.)

1604.

[489.] On Sept. 30 a large star like a ball appeared in the sidereal division of μ^2 Scorpii. It vanished in the S.W. in November. On Jan. 14, 1605, it reappeared in the S.E. About March it became dim.—(Biot*; Williams, 93.)

1609.

[490.] A great star appeared in the S.W. The tail had 4 rays.—(Biot*; Williams, 93.)

1618 (ii).

[491.] Between Nov. 10 and 26 a comet was seen by Figueroes at Ispahan, coincidently with the apparition of Comet iii. of this year. In consequence of the comet's Southerly motion the head was not generally, if at all, seen in Europe—only the tail. Kepler and Blancanus were the chief observers who saw the latter. Kepler *guessed* that on Nov. 10 the nucleus was in 16° of Scorpio, with a latitude of 8° S.; and that on Nov. 20 it was near the head of Centaur. At Rome the tail was seen to be 40° long on Nov. 18. It was last seen on the 29th. The observers (Jesuits) note that in 11 days the proper motion of the tail caused it to pass over 24° from Crater towards α Hydræ.—(Pingré, *Comét.*, ii. 57.) On Nov. 24 a white vapour 20 cubits long was seen in the S.E. It extended across the sidereal division of γ Corvi. It entered the sidereal division of α Crateris and disappeared after 19 days. (Williams, 93.) The Chinese record "a star like a white flower" as being visible on Dec. 5 of this year. It may be well to mention here that Cooper, in his *Cometic Orbits* (p. 77), appears to have fallen into a mistake relative to the comets of this year, which others have copied. He gives the elements of the iii^rd^ comet, and appends notes referring to the ii^nd^ and iii^rd^ as if they were one and the same object.

1619.

[492.] In February a comet was seen in the S. E.: it was 100 cubits long, curved and pointed.—(Biot; Williams, 87.)

1625.

[493.] From Jan. 26 to Feb. 12 a comet was observed by Schickhardt in Eridanus and Cetus.—(*Astronomische Nachrichten*, vol. ii. No. 31. April 1823.) It was Olbers who rescued this comet from oblivion.

1628.

[494.] A comet appeared, mentioned by Ripamontius.—(*Astronomische Nachrichten*, vol. xii. No. 277. April 29, 1835.)

1630.

[495.] A comet appeared: also mentioned by Ripamontius, and by him associated with a pestilence.—(*Astronomische Nachrichten*, vol. xii. No. 277. April 29, 1835.)

1639.

[496.] On Oct. 27 a comet with a small tail was seen in Canis Major by Placidus de Titis—(*Astronomische Nachrichten*, vol. viii. No. 171. January 1830.) In the autumn a comet was seen in the sidereal division of δ Orionis.—(Biot; Williams, 87.)

1640.

[497.] On Dec. 12 a comet was seen.—(Biot; Williams, 87.)

1647.

[498.] On Sept. 29 a comet was seen soon after sunset in Coma Berenicis. Its longitude was 188° and its latitude + 26°. It was 12° long and lasted one week, traversing Boötes, Northwards of Arcturus, to Corona Borealis, in a line sensibly parallel to the equator.—(Hevelius, *Cometographia*, p. 463.)

1699 (ii).

[499.] On Oct. 26 Godefroi Kirch observed a faint comet in the poop of Argo; in longitude 122° 34′, and latitude − 40° 38′. It was visible to the naked eye, and its motion was sensibly Southwards. Kirch was unable to find it on any subsequent night.—(*Miscellanea Berolinensia*, v. 50.)

1702 (i).

[500.] Numerous navigators in the Southern hemisphere report seeing a comet between Feb. 20 and March 1. On Feb. 28 the tail was 43° long. At 8 P.M., in latitude 15° 10′ N., and longitude 116° 45′ E. of Teneriffe, the comet bore S. of W. 20° 30′, altitude 8° 40′. On all occasions it was seen in the evening, after sunset. Maraldi at Rome saw the tail for several days at the end of February and the beginning of March.—(Struyck, *Vervolg van de Beschryving der Staarts Sternen*. 4to. Amsterdam 1753, p. 50.)

1733.

[501.] On May 17 and 18 a comet was seen by several navigators off the Cape of Good Hope, bearing N.W. ¼W. It was observed for more than an hour, until it went below the horizon.—(Struyck, *Vervolg*, p. 61.)

1742 (ii).

[502.] On April 11, in the morning, a comet was seen in the S.E. by several Dutch navigators at sea in the Southern ocean. On April 14 the tail was 30° long.—(Struyck, *Vervolg.*)

1748 (iii).

[503.] On April 24 a Dutch navigator, at the Cape of Good Hope, saw a comet, at the beginning of Aries, rise in the E. ½N.E. at 4^h A.M. This is probably the comet, rendered invisible at the Cape by a Northerly motion, which Kindermanns saw on April 28, at 2^h A.M., at an elevation of 8° above the horizon, in a straight line with (it would seem) δ and η Trianguli and the brightest star of Aries, in Longitude 80°, Latitude + 28°, and Declination + 50°. On May 3, between 11^h and midnight, the comet was near Perseus, and circumpolar.—(Struyck, *Vervolg*, p. 100.)

1750.

[504.] Between Jan. 21 and 25 Wargentin observed a comet below ϵ and θ Pegasi.—(*Tables Astronomiques de Berlin*, i. 35.)

1783 (ii).

[505.] On Dec. 18, 1783, Sir W. Herschel observed a nebula 1^m preceding δ Ceti, and ½°N. of that star. He describes it as "small and cometic." In his son's great *Catalogue of Nebulæ* 1864, this object is set down as really a comet, not having been since found, though looked for.

1808 (i).

[506.] On Feb. 6 Pons discovered a small faint comet between the neck of Serpens and ["la languette" of] Libra. It was only visible for 3 days, becoming lost in the moonlight. Its movement was rapid and towards the S.—(*Monatliche Correspondenz*, vol. xviii. p. 252. Sept. 1808. *Ast. Nach.*, vol. vii. No. 149. Jan. 1829.)

1808 (iv).

[507.] On July 3 Pons discovered a comet in Camelopardus: it was observed only on that night and July 5. Its position on July 3, at $15^h\ 4^m\ 26^s$ Marseilles M.T., was R.A. $3^h\ 10^m\ 10^s$, and Decl. + 56° 36′: on July 5 at $15^h\ 8^m\ 58^s$ the R.A. was $3^h\ 31^m\ 46^s$, and Decl. + 58° 19′.—(*Monatliche Correspondenz*, vol. xviii. p. 249. Sept. 1808.)

1839.

[508.] On July 14 and 17 an extremely faint comet was seen at the Roman College. It was in Draco, and appeared like a double nebula, or as if divided into 2 branches. The following positions were taken: July $14^d\ 10^h\ 1^m$, R.A. $12^h\ 9^m\ 41^s$, Decl. + 70° 28·6′; July $17^d\ 10^h\ 6^m$, R.A. $11^h\ 50^m\ 27^s$, Decl. + 70° 39·3′.—(*Memoria...Osservazioni fatte...in Collegio Romano*, 1839, p. 38.)

1846 (ix).

[509.] On Oct. 18 Hind observed a comet in Coma Berenicis for more than an hour. Its altitude was small, and being in the morning twilight it was never seen again. Its exact position at $16^h\ 15^m\ 11^s$ G.M.T. was R.A. $11^h\ 59^m\ 49^s$, Decl. + 14° 59′ 32″. Its motion was increasing in R.A. at the rate of about

4^m a day, and diminishing in Decl. at the rate of about 11′ a day.—(*Month. Not.*, vii. 162. Nov. 1846.)

1849 (iv).

[510.] On Nov. 15, at sea, in the S. Atlantic, a comet was seen from the U.S. Ship *Maryland*, with a nucleus as bright as Mars, and with a tail, curved and pointing to the S.W., nearly 1° long. From the notes of Captain Horner, Mr. Hind worked out the following position: at $9^h\ 49^m$ G.M.T., R.A $20^h\ 36{\cdot}6^m$, Decl. + 4° 18′. —(*Month. Not.*, x. 122 and 192. March, &c., 1850.)

1854 (iii).

[511.] On March 16 a bright nebulous object was seen by Brorsen. Its position at $8^h\ 15^m\ 34^s$ Senftenburg M.T. was: R.A. $2^h\ 30^m\ 12^s$, and Decl. + 1° 11·2′.—(*Ast. Nach.*, vol. xxxviii. No. 897. March 27, 1854.)

1855 (ii).

[512.] On May 16, whilst searching for Di Vico's comet, Goldschmidt at Paris found a comet in R.A. $21^h\ 41^m\ 45^s$, Decl. − 15° 38′, which he announced as positively the missing comet (*Ast. Nach.*, vol. xli. No. 978. Aug. 25, 1855). No confirmation of the discovery was obtained, and astronomers, though they did not doubt that *a* comet had been seen, decidedly doubted that it was the periodical comet of Di Vico which Goldschmidt had found. Twelve years afterwards Winnecke claimed to have cleared up the uncertainty by determining that the comet seen by Goldschmidt was a prior return of comet ii. of 1867 (*Ast. Nach.*, vol. lxix. No. 1645. June 20, 1867): but this theory has been distinctly disproved by Von Asten (*Ast. Nach.*, vol. lxxxii. No. 1962. Nov. 3, 1873.)

1856 (i).

[513.] In January a comet was seen in the N.W. sky at Panama.—(Letter in the *Morning Herald*. *Month. Not.*, vol. xvii. p. 114. Feb. 1857.)

1856 (ii).

[514.] On Aug. 7 an object, supposed to be a comet, was seen in Virgo by E. J. Lowe.—(*Month. Not.*, vol. xvii. p. 114. Feb. 1857.) A comet was also seen at Arequipa, in Peru, for a fortnight previous to Aug. 21 for 2 hours after sunset.—(Letter in the *Times*, Oct. 8, 1856.)

1859 (i).

[515.] In Feb. a very faint comet was seen by Slater, in R.A. $11^h\ 48^m$: Decl. + 19° 49′. He saw it again on May 7 and 22, when it had become fainter, not being visible with any aperture below 11½ inches. Its movement was very slow, and seemed to be in a northerly direction.—(*Month. Not.*, vol. xix. p. 291. June 1859.)

1860 (v).

[516.] On November 14, Tuttle at Cambridge U.S. observed a very faint comet near the Pole-Star. It was not questioned till 8 years afterwards but that this was identical with comet iv. of 1860.—(*Ast. Nach.*, vol. lv. No. 1301. March 30, 1861: *ib.*, vol. lxxiii. No. 1734. Jan. 16, 1869: *ib.*, vol. lxxiii. No. 1740. Feb. 16, 1869: *ib.*, vol. lxxv. No. 1787. Jan. 12, 1870.)

1865 (ii).

[517.] *Encke's comet.* This object was discovered by Tebbutt at Windsor, N.S.W., on June 24. It was very faint, and was seen only on that occasion and on June 29. Its observed place on the 24th is noted to have differed very much from that assigned by calculation.—(*Ast. Nach.*, vol. lxv. No. 1551. Oct. 6, 1865.)

1865 iii. and iv. (?).

[518 and 519.] On Aug. 27, two comets were seen by [E. J.] Lowe at 8^h 30^m P.M. The position of the first was, R.A. 15^h 15^m: Decl. $-3°$ $50'$. And of the second, R.A. 15^h 0^m: Decl. $-7°$ $30'$. "From an account I see in the newspapers of a comet seen at 3^h 45^m A.M. in the E. '*three days ago*' [no date given !] I have little doubt this is one of the comets I saw in August."—(*Month. Not.*, vol. xxv. p. 278. Oct. 1865.) [This is a *very* slovenly record.]

1871 (vi).

[520.] On December 29, at 6^h 15^m Milan M.T., Tempel observed a faint comet in R.A. 19^h 51^m 32^s: decl. $+29°$ $56'$.—(*Ast. Nach.*, vol. lxxviii. No. 1872. Jan. 3, 1872.)

1872.

[521.] On Dec. 2, Pogson at Madras, in consequence of a telegram from Klinkerfues of Göttingen (in these words, "Biela touched Earth on Nov. 27; search near θ Centauri"), sought and found a comet. At 17^h 31^m Madras M.T. its R.A. was 14^h 7^m 12^s: Decl. $-34°$ $45'$. It was "bright, circular, about $45''$ in diameter: a very decided nucleus, but no tail discernible in strong twilight and cloudy sky." On the following morning at 17^h 3^m the comet was seen again in R.A. 14^h 21^m 55^s: Decl. $-35°$ $4'$. The description was, "bright, round, and about $75''$ in diameter. A short faint tail seen about $7{\cdot}4'$ in length." Bad weather and the advance of twilight rendered subsequent observations impossible. This was presumed to have been the long-lost *Biela's comet*, but the idea has been disproved by Bruhns. (*Month. Not.*, vol. xxxiii. p. 116. Dec. 1872: *Ast. Nach.*, vol. lxxx. No. 1918. Jan. 16, 1873: *ib.*, vol. lxxxiv. No. 2004. Aug. 11, 1874: *ib.*, vol. lxxxvi. No. 2054. Sept. 10, 1875.)

OBJECTS RECORDED AS NEBULÆ, BUT WHICH MAY POSSIBLY HAVE BEEN COMETS.

614 H. R.A. for 1860: 2^h 44^m 6^s: Decl. $+36°$ $55{\cdot}7'$: observed by Bessel. Looked for and not found by D'Arrest, who supposes it to have been a comet.

2094 H. R.A. for 1860: 10^h 17^m 5^s: Decl. $+27°$ $43{\cdot}9'$: observed by Sir J. Herschel. Looked for 6 times and not found by Lord Rosse. "This then was a comet or a lost nebula."

50 ♅ III. On March 19, 1784, Sir W. Herschel observed an exceedingly faint nebula, 3^m 15^s following 45 Canum, and 4^m south. Sir J. Herschel stated that he had found a memorandum that this nebula is lost, and was probably a comet.

3550 H. R.A. for 1860 : 13^h 21^m 13^s : Decl. + 6° 43·4′ : observed by D'Arrest, but "not found again on Feb. 19, 1863. Sky perfectly clear. Perhaps a comet."

Hevelius, in his *Prodromus Astronomiæ*, states that he once saw in the head of Hercules, near α, a nebula. This was searched for unsuccessfully by Messier. The nearest object is 901 ♅ II, but this would be quite beyond the reach of the telescopes used in the time of Hevelius, so it must have been a comet that he saw.—(Smyth, *Cycle*, ii. 385.) I have not succeeded in recovering this statement.

BOOK V.

CHRONOLOGICAL ASTRONOMY.

CHAPTER I.

What Time is.—The Sidereal Day.—Its length.—Difference between the Sidereal Day and the Mean Solar Day.—The Equation of Time.—The anomalistic Year.—Use of the Gnomon.—Length of the Solar Year according to different observers.—The Julian Calendar.—The Gregorian Calendar.—Old Style versus New Style.—Romish miracles.—Table of differences of the Styles.

TIME is, strictly speaking, of indefinite duration; we are, therefore, obliged to choose some arbitrary unit by means of which a measurement of time may be effected. For short intervals, the diurnal rotation on its axis of the globe we inhabit, and for longer intervals, the annual revolution of the Earth around the Sun, are the standards of measurement which we employ; but any events which take place at equal intervals of time would serve the purpose of a chronometrical register. Thus, the number of concentric rings in the trunks of trees; the number of rings on the horns of cattle; the successive disappearance of marks from the teeth of horses; the pulsations of the heart; the flowing of a certain quantity of water from one vessel to another; the oscillations of a pendulum, are all such recurring events as may be employed to measure time: but, in practice, the solar day is a natural interval of time, which the domestic habits of man force upon him; and accordingly we find that this unit of measurement is the one almost universally adopted.

The space of time in which the Earth rotates on its axis is known to us as the *Sidereal Day;* it is determined by 2 consecutive passages of a star across the meridian of the place of observation, and is subdivided into 24 equal portions, called *sidereal hours,* each of which is made up of 60 *sidereal minutes,* &c. The sidereal day may be otherwise defined to be the time occupied by the celestial sphere in making one complete revolution. The duration of this interval can be shewn by theory to be all but invariable, and the actual comparisons of observations made on numerous stars, in widely different ages of the world, corroborate this conclusion. Here we have, then, a chronometric unit far surpassing in accuracy anything that can be artificially contrived. Laplace indeed thought that he had ascertained, from a careful comparison of modern with ancient observations, that the length of the sidereal day could not have altered so much as $\frac{1}{100}$ of a second in upwards of 2000 years, but more recent investigation has rendered it necessary for us to qualify older assertions on this subject, for it is now supposed that owing to friction due to the Tides the sidereal day is now shorter by not quite $\frac{1}{80}$ of a second than it was 2500 years ago. But notwithstanding this, the sidereal day may be regarded as possessing practically that indispensable qualification for a standard unit, *invariability.*

The *Solar Day* is reckoned by the interval elapsing between 2 successive meridian passages of the Sun.

The orbit of the Earth not being exactly circular, (and its axis being considerably inclined,) it follows that the daily velocity of our globe round the Sun, or, what for our purpose is the same, the daily apparent motion of the Sun through the Zodiac, is not uniform [a], and the length of the solar day, therefore, varies at different seasons of the year; this variable interval is called the *Apparent Solar Day,* and time so reckoned is *Apparent Time.* In order to obviate the inconvenience which would attend the use of such a day in reckoning time, astronomers have agreed to suppose the existence of an imaginary sun moving in the equator, with a velocity equal to the Sun's average velocity in the ecliptic.

[a] The average daily motion is 0° 59′ 8·2″, but with the Sun in perigee, in January, it amounts to 1° 1′ 9·9″; with the Sun in apogee, in July, it is only 0° 57′ 11·5″.

When this fictitious or *mean sun* comes to the meridian, it is said to be *mean noon;* and when the true meridian passage of the Sun takes place, it is *apparent noon:* the interval between the two mean passages being called the *mean solar day.* If the Sun were, like a star, stationary in the heavens, then it is clear, from what has been said above, that the solar and sidereal days would be equal; but since the Sun passes from W. to E., through a whole circle (that is to say, through 360°) in 365·2422 days—it moves Eastwards about 59′ 8·2″ daily. While, therefore, the Earth is revolving on its axis, the Sun is moving in the same direction; so that when we have come round again to the meridian from which we started, we do not find the Sun there, but nearly 1° to the Eastward; and the Earth must perform a part of a 2nd revolution before we can come under the Sun again. Thus it is that the mean solar day is longer than the sidereal day in the ratio of 1·00273791 to 1: the former being taken at exactly $24^h\ 0^m\ 0^s$, the latter, expressed in mean solar time, is $23^h\ 56^m\ 4{\cdot}091^s$, or $0{\cdot}99726957^d$. Clocks regulated to keep sidereal time are in general use in astronomical observatories—one revolution of the hands of the clock through 360°, or 24^h, thus representing 1 complete revolution of the heavens; but it is obvious that a sidereal hour is shorter than a solar hour, the difference being $9{\cdot}8256^s$. 24^h of mean solar time are equal to $24^h\ 3^m\ 56{\cdot}55^s$ of sidereal time. In consequence of the sidereal day being $3^m\ 55{\cdot}91^s$ shorter reckoned in mean solar time than the mean solar day, the stars all pass the meridian $3^m\ 55{\cdot}91^s$ earlier every day. This gaining of the stars upon the Sun is called the *Acceleration of Sidereal upon Mean Time:* an obvious consequence of this acceleration is, that the aspect of the heavens varies at different times of the year, for those stars which at one time are seen on the meridian at midnight, pass it at 9^h in the evening after about 6 weeks.

The clocks we have in common use are all regulated to mean time, and will therefore shew 12 o'clock sometimes before and sometimes after the true Sun has reached the meridian: this difference between mean time and apparent time is called the *Equation of Time,* and tables are constructed for the purpose of reducing the one to the other. Four times a year, the correction is zero, and the true and imaginary Suns coincide. Twice in the same period the clock is before the Sun, and twice after it. The

EQUATION OF TIME AT APPARENT NOON.

Day of Month.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
	+	+	+	+	−	−	+	+	−	−	−	−
	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.
1	3 51	13 51	12 32	3 55	3 3	2 30	3 29	6 4	0 6	10 18	16 17	10 46
3	4 47	14 6	12 7	3 19	3 16	2 11	3 52	5 56	0 44	10 56	16 18	9 59
5	5 42	[illegible] 16	11 41	2 44	3 28	1 50	4 14	5 45	1 23	11 32	16 16	9 11
7	6 35	[illegible] 24	11 12	2 9	3 38	1 29	4 34	5 32	2 3	12 7	16 11	8 20
9	7 25	14 28	10 42	1 36	3 45	1 6	4 53	5 17	2 44	12 41	16 2	7 27
11	8 14	14 29	10 11	1 3	3 50	0 43	5 10	4 59	3 26	13 12	15 50	6 32
13	9 0	14 27	9 38	0 31	3 53	0 18	5 25	4 39	4 8	13 42	15 34	6 36
15	9 43	14 22	9 4	0 0	3 53	+ 0 6	5 38	4 17	4 50	14 9	15 15	4 38
17	10 23	14 14	8 29	− 0 29	3 52	0 32	5 49	3 52	5 33	14 34	14 53	3 40
19	11 1	14 3	7 53	0 56	3 48	0 58	5 58	3 26	6 15	14 57	14 27	2 40
21	11 36	13 50	7 17	1 22	3 41	1 24	6 5	2 58	6 57	15 17	13 58	1 40
23	12 7	13 34	6 41	1 46	3 33	1 50	6 10	2 28	7 39	15 34	13 25	0 40
25	12 36	13 15	6 4	2 8	3 22	2 15	6 13	1 56	8 20	15 49	12 50	+ 0 19
27	13 1	12 55	5 27	2 28	3 9	2 41	6 14	1 23	9 0	16 1	12 11	1 19
29	13 24		4 50	2 47	2 55	3 5	6 12	0 48	9 40	16 9	11 30	2 18
31	13 43		4 14		2 38		6 7	0 12		16 15		3 16

equation reaches its maximum about Feb. 10, when a correction of about $14^m\ 28^s$ is required to reduce apparent to mean solar time; or, in other words, the mean sun is on the meridian $14^m\ 28^s$ before the true Sun. On April 15 there is no equation, the real and fictitious Suns being on the meridian at the same moment. Towards the middle of May the equation again reaches a maximum of $3^m\ 53^s$, but becomes reduced to zero by June 15. Another maximum occurs about July 27, when a correction of $6^m\ 14^s$ must be added to the apparent solar time. On Sept. 1 the equation is again at zero, but increases from that time until the beginning of November, when the correction amounts to $16^m\ 18^s$, subtractive from apparent time. Another zero takes place about Dec. 25, and this completes the circuit.

In France, until 1816, apparent time was used, and the confusion arising from this practice may be readily imagined. Arago relates that he was once told by Delambre, that he had frequently heard the different public clocks striking the same hour with a variation of 30 minutes. At the time of the change, the Prefect of the Seine refused to sign the necessary order, fearing an insurrection amongst the lower classes; the worthy magistrate's fears however proved to be groundless. Especially were the watchmakers thankful for the change; under the old system, all in vain was it that they tried to explain to their enraged customers, when they came to complain of the watches they had bought, that it was not the watches but the Sun which was in fault.

The interval of time which elapses from the moment when the Sun leaves a fixed star until it returns to it again, constitutes the *sidereal year*, and consists in solar time of $365^d\ 6^h\ 9^m\ 9{\cdot}6^s$; therefore the sidereal year is longer than the mean solar year. The latter is the interval of time which elapses between 2 successive passages of the Sun through the same equinox. If the equinoxes were fixed points, then this period would be identical with the sidereal revolution of the Earth; but since these points are possessed of a retrograde motion from East to West of $50{\cdot}27''$ annually, it follows that the Sun returns to the equinox sooner every year by a period equal to the time which it takes to traverse $50{\cdot}27''$ of arc, or by $20^m\ 22{\cdot}9^s$ of time. The mean solar year is therefore $20^m\ 22{\cdot}9^s$ shorter than the sidereal year, or its length is $365^d\ 5^h\ 48^m\ 46{\cdot}7^s$. In consequence

of lack of uniformity in the motion of the equinoctial points (on account of planetary perturbation), a variation takes place in the length of the mean solar year, which is now diminishing in length at the rate of $0{\cdot}595^{s}$ per century. This variation, however, will not always be in operation.

The line of apsides of the Earth's orbit is subject to an annual progressive motion of $11{\cdot}778''$ (Delambre). If the Earth, then, be supposed to start from perihelion, it will require a longer interval of time than the sidereal period to reach perihelion again, and the excess will be equal to the time necessary for the Earth to describe $11{\cdot}8''$ of its orbit; this it would do in $4^{m}\ 39{\cdot}7^{s}$, which quantity must be added to the sidereal period before we can ascertain the interval between 2 successive returns to perihelion. The result then is a period of $365^{d}\ 6^{h}\ 13^{m}\ 49{\cdot}3^{s}$ ($365{\cdot}2595981$ mean solar days), which is called the *anomalistic year*.

The manner in which the ancients ascertained the length of the year was by means of the *gnomon* or *stylus*—a vertical rod standing on a smooth plane which had a meridian line described on it. The time when the shadow was shortest would indicate the day of the summer solstice, and the number of days which elapsed until the shadow returned to the same length, would be the number of days in the year. This interval having been found to be 365 days, 365 days was the period adopted for the length of the common year, or nearly 6 hours less than the true length. Such a difference would, after the lapse of some time, throw everything into confusion; for, supposing that in any one year the summer solstice fell on June 21, after the lapse of 4 years it would fall on the 22nd, in another period of 4 years it would happen on the 23rd, and so on. Some inhabitant of Thebes in Egypt is said to have been the first to have noticed the necessity of an addition of 6 hours to the 365 days in order to make the year coincide with the annual course of the Sun. In the time of Democritus (450 B.C.), 365¼ days was supposed to be the length of the year; Eudoxus made it somewhat longer, and, according to Diodorus Siculus, Œnopides of Chios fixed it at $365^{d}\ 8^{h}\ 48^{m}$. Hipparchus, by means of his own observations, found the length then in use (365¼ days) to be too great by $4^{m}\ 48^{s}$. Ptolemy also examined the subject, but came to no definite determination. Towards the close of the 9th century, the Arabian prince Alba-

tegnius, from observations of his own, considered that the length given by Hipparchus was still too great by some $8^m 48^s$; he accordingly assigned a new determination in his work, *De Scientiâ Stellarum*. The following table exhibits some of the principal determinations which have been arrived at, both in ancient and modern times:—

	d.	h.	m.	s.
Ancient Egyptian	365	0	0	0
Euctemon and Meton	365	6	18	57
Calippus, &c.	365	6	0	0
Hipparchus	365	5	55	12
Hindu	365	5	50	30
Albategnius	365	5	46	24
Alphonsine Tables, 1252	365	5	49	16
Walther	365	5	48	50
Copernicus, 1543	365	5	49	6
Tycho Brahe, 1602	365	5	48	45½
Kepler	365	5	48	57·6
J. Cassini, 1743	365	5	48	52·4
Flamsteed	365	5	48	57·5
Halley	365	5	48	54·8
La Caille	365	5	48	49
Delambre	365	5	48	51·6
Laplace	365	5	48	49·7
Bessel	365	5	48	47·8
Hansen and Olufsen	365	5	48	46·15
Le Verrier	365	5	48	46·05

We have seen that the mean solar year does not contain a whole number of days, but that a fractional quantity is appended; that is to say, its length is thus expressed—365·2422414 days. 100 years of 365 days each would contain 36,500 days, or would fall short of 365 revolutions of the Sun by about 24 days. In order to remedy this state of things, Julius Cæsar, who was as distinguished for the varied nature of his mental attainments as for his skill in military affairs, called to his aid the Egyptian astronomer Sosigenes, and they both set to work to reform the calendar. They introduced an additional day every 4th year into the month of February, thereby making 25 additional days in the century. This 4th year was termed *bissextile*, because the 6th day before the calends of March was reckoned twice, and in this year, therefore, February was made to consist of 29 days. This almost perfect arrangement, which was called from its author

the Julian style, prevailed generally throughout the Christian world till the close of the 16th century[b]. The calendar of Julius Cæsar was defective in this particular,—that the solar year consists of $365^d\ 5^h\ 48\frac{3}{4}^m$, and not of $365^d\ 6^h$, as was supposed in his time, and therefore there was a difference of 11^m between the apparent and true years. At the time of Gregory XIII. this difference had so accumulated as to amount to more than 10 days, the vernal equinox falling, in 1582, on March 11 instead of 21, at which it was in the year 325 A.D., when the Council of Nicæa was held. At this council uniformity in the keeping of Easter was decreed, and the first Sunday after the first Full Moon next following the vernal equinox became tacitly recognised. "As certain other festivals of the Romish Church were appointed at particular seasons of the year, confusion would result from such want of constancy between any fixed date and a particular season of the year. Suppose, for example, that a festival, accompanied by numerous religious ceremonies, was decreed by the Church to be held at the time when the Sun crossed the equator in the spring (an event hailed with great joy as the harbinger of the return of summer), and that in the year 325, March 21 was designated as the time for holding the festival, since at that period it was on March 21 when the Sun reached the equinox; the next year the Sun would reach the equinox a little sooner than the 21st, only 11^m indeed, but still amounting to 10 days in 1200 years; that is, in 1582 the Sun reached the equinox on March 11. If, therefore, they continued to observe the 21st as a religious festival in honour of this event, they would commit the absurdity of celebrating it 10 days after it had passed by." This anomaly Gregory XIII. undertook to correct, and this he did with practically perfect success; he ordained that 10 days should be left out of the current year in order to bring back the equinox to March 21, and in order to keep it on that day, he prescribed the following rule:—*Every year, not being a secular year, divisible by* 4, *to be a bissextile, or leap year, containing* 366 *days: every year not so divisible to consist of only* 365 *days: every secular year divisible by* 400 (such as 1600, 2000, &c.), *to be a bissextile, or leap year, containing* 366 *days: every secular year not so divisible* (such as 1800, 1900, &c.) *to consist of* 365 *days.* If

[b] The Julian error amounted to +0·00778 day annually, or 1 whole day in 129 years.

every 4^{th} year were to consist of 366 days, a century would be too long by $\frac{1}{4}$ of a day: that is to say, we should have allowed 1 whole day in 100 years instead of only $\frac{3}{4}$; in 400 years this would have amounted to 1 day; this will explain why a day is to be intercalated every 4^{th} secular year, the other secular years containing only 365 days. We will now perform some short calculations to see how near this rule is to the truth, by comparing 10,000 Gregorian with 10,000 Tropical (or solar) years. In 10,000 the numbers not divisible by 4 will be $\frac{3}{4}$ of 10,000, or 7500; those divisible by 100, but not by 400, will in like manner be $\frac{3}{4}$ of 100, or 75; so that in the 10,000 years in question, 7575 consist of 365 days, and the remaining 2425 of 366, producing in all 3,652,425 days. Dividing this number by 10,000, we get 365·2425 as the mean Gregorian length of the solar year. The actual value of the latter being 365·2422, the error in 10,000 years amounts to 2·6, or $2^d\ 14^h\ 24^m$, or 1 day in 3846 years, or 22^s annually—a quantity which we can, without inconvenience, disregard[c]. But even this error, trifling as it is, may be still further eliminated by declaring those years divisible only by 4000, to be common and not bissextile years; this would make the error only 1 day in 100,000 Gregorian years.

The Gregorian remedy was proposed by Cardinal Pierre D'Ailly to the Council of Constance, and to Pope John XXIII. as early as 1414. About the same time Cardinal Cusa wrote on the subject. Roger Bacon had previously made a formal proposition relating to it. Sextus IV. being desirous of realising the plan, called to his court Regiomontanus, whose death in 1476 prevented progress. When the Council of Trent separated in 1563 it recommended the Pope to take up the matter[d].

The Julian calendar was introduced in the year 44 B.C., which Cæsar ordered should commence on Jan. 1, being the day of the New Moon immediately following the winter solstice of the preceding year: this year was thus made to consist of 445 days, and was known as "the year of confusion." Cæsar did not live to carry out in person the reform he had decreed, and the consequence was that real and great confusion ensued. We are not acquainted

[c] Hansen's investigations (*Tables du Soleil*, p. 1) imply the necessity of revising to a trifling extent these figures, but I have not deemed it worth while to do this for my present purpose.

[d] Arago, *Pop. Ast.*, vol. ii. p. 744.

with the terms of the edict which he promulgated, but we are led to infer that it was not so explicit as it ought to have been, and that it contained some expressions relating to "every 4th year" which were not clearly enunciated. The consequence was, that Cæsar's successors counted the leap year just elapsed as No. 1 of the quadrennial period, and intercalated every *third* instead of every 4th year. "This erroneous practice continued during 36 years, in which, therefore, 12 instead of 9 days were intercalated, and an error of 3 days produced; to rectify which Augustus ordered the suspension of all intercalation during three complete *quadrennia*,—thus restoring, as may be presumed his intention to have been, the Julian dates for the future, and re-establishing the Julian system, which was never after vitiated by any error till the epoch when its own inherent defects gave occasion to the Gregorian reformation. . . . And starting from *this* [the period of the Augustan reform] as a certain fact, (for the statements of the transaction by classical authors are not so precise as to leave *absolutely no doubt* as to the previous intermediate years), astronomers and chronologists have agreed to reckon backwards in unbroken succession on this principle, and thus to carry the Julian chronology into past time, *as if* it had never suffered such interruption, and *as if* it were certain [which it is not, though we conceive the balance of probabilities to incline that way] that Cæsar, by way of securing the intercalation as a matter of precedent, made his initial year, 45 B.C., a leap year. Whenever, therefore, in the relation of any event, either in ancient history or in modern, previous to the change of style, the time is specified in our modern nomenclature, it is always to be understood as having been identified with the assigned date by threading the mazes (often very tangled and obscure ones) of special and national chronology, and referring the day of its occurrence to its place in the Julian system *so interpreted* [e]." The reformed Gregorian calendar was published to the world in 1582, the Pope at the same time issuing a decree commanding its observance throughout Christendom. His mandate met with great opposition from those Catholic powers of Europe which did not recognise the Papal supremacy; but in Romish countries it was soon adopted. It

[e] Herschel, *Outlines of Ast.*, p. 675.

was not established in Great Britain till 1752, when an Act of Parliament was passed enjoining its use[f]. As 170 years had elapsed since the new style had been first brought into use, it became necessary to suppress 11 days, in order to set right the equinox; this was effected by calling the day after Sept. 2 the 14th. By the same Act it was decreed that Jan. 1 should be the commencement of the year, instead of March 25, as it had been heretofore. We shall now see the practical effect of these changes. In order to make any date given in the O.S. comparable with our present mode of reckoning, we must add thereto 11 days: thus, April 24 O.S. is equivalent to May 5 N.S. If any event happened between Jan. 1 and March 25, the date of the year will be advanced 1: thus, March 21 1864 O.S. will be April 2 1865 N.S.; bearing in mind that the difference between the two styles, which in 1752 was 11 days, is now 12. Russia and the Greek Church generally still adhere to the old style, consequently their dates are thus expressed :—

$$1880\ \frac{\text{May 23.}}{\text{June 4.}}$$

A sweeping change such as was involved in this Gregorian revision was, as might have been anticipated, received with great dissatisfaction by the English nation at large, but more especially by the lower orders, who considered that they had been robbed of 11 clear days. The inconveniences to which everybody was subjected (because every kind of festival and anniversary was disturbed) were, moreover, by no means agreeable to the feelings of most people. Professor De Morgan, on the authority of a scientific friend, related the following anecdote:—"A worthy couple in a country town, scandalised by the change of style in 1752, continued for many years to attempt the observance of Good Friday on the old day. To this end they walked seriously and in full dress to the church door, at which the gentleman rapped with his stick; on finding no admittance, they walked as seriously back again, and read the Service at home. But on the new

[f] 24 Geo. II. c. 23. It is not generally known that an effort was made to reform the Calendar as early as the reign of Queen Elizabeth. On March 16, 1584-5, a bill was introduced into the House of Lords for the purpose. It was read a second time on March 18, and then appears to have been dropped, as we have no further notice of it. (*Eng. Cycl.*, art. "Kalendar."

and spurious Good Friday they took pains to make such a festival at their house as would convince the neighbours that their Lent was either ended or in abeyance." But there must have been some days of comfort, for between 1752 and 1800 there were 18 years in which the old and new Easter Day coincided. This may happen occasionally, and will do so, though less and less frequently, till 2698 A.D., when it will occur for the last time.

Previous to the change of style there existed a wide-spread superstition in England that, at the moment when Christmas Day began, the cattle always fell on their knees in their stables; it was averred, however, that the animal creation refused to obey the Papal bull, and still continued their prostrations on the Christmas eve of the Old Style. In Romish countries, however, even inanimate things agreed to change their habits; for Riccioli positively assures us that the blood of St. Januarius, which under the old order of things always liquefied punctually on Sept. 19 (?), immediately changed its day of liquefaction to Sept. 9, O.S., in order to conform to Sept. 19, N.S., thereby putting itself back 10 days, that it might obey the Pope's mandate! But this was not all; for Riccioli goes on to add that a certain twig, which always budded on Christmas Day, O.S., thence budded on Dec. 15, N.S., for the same reason[g]!

In England the members of the Calendar-Reforming Government were pursued and mobbed in the streets of London, the populace demanding the restoration of the 11 days of which they supposed they had been illegally deprived. The illness and subsequent death of Bradley, the astronomer, who had assisted the Government with his advice, was looked upon as a judgment from Heaven[h].

On the subject of the Calendar generally some useful information will be found in the work cited below[i].

The following is a table of the differences between the old and new styles, for the under-mentioned periods:—

[g] *Companion to the Almanac*, 1845, p. 19.

[h] A friend however has pointed out to me that Bradley lived 10 years longer, for he did not die till 1762.

[i] *Astronomy without Mathematics*. By Sir E. Beckett, Bart. The Theory of the Equation of Time is very clearly explained in Linnington's *Compendium of Astronomy*, p. 231.

Date.	Difference.	Date.	Difference.
1500—1700	10 days.	2900—3000	20 days.
1700—1800	11 ,,	3000—3100	21 ,,
1800—1900	12 ,,	3100—3300	22 ,,
1900—2100	13 ,,	3300—3400	23 ,,
2100—2200	14 ,,	3400—3500	24 ,,
2200—2300	15 ,,	3500—3700	25 ,,
2300—2500	16 ,,	3700—3800	26 ,,
2500—2600	17 ,,	3800—3900	27 ,,
2600—2700	18 ,,	3900—4100	28 ,,
2700—2900	19 ,,	&c.	&c.

CHAPTER II.

Hours.—Commencement of the days.—Usage of different nations.—Days.—Weeks.—Origin of the English names for the days of the week.—The Egyptian 7-day period.—The Roman week.—Months.—Memoranda on the months.—Years.—The Egyptian year.—The Jewish year.—The Greek year.—The Roman year.—The Roman Calendar and the reforms it underwent.—The French revolutionary Calendar.—The year.—Its sub-divisions into quarters.—Quarter-days.

WE have now to consider the different divisions of time which are in use, beginning with—

Hours.—I have already mentioned that a day is divided into 24 equal portions, called hours; each of these contains 60 minutes, and each minute 60 seconds[a]. It is now quite impossible to assign any date to the origin of this custom, so completely is it lost in the obscurity of antiquity. Although the duodecimal division of the day is so universal, yet different usages have prevailed in different countries relative to the enumeration of those hours. Some nations have counted the hours consecutively from 1 to 24; others have divided the hours into 2 series of 12 each; whilst in France, during the revolutionary period following the year 1793, a decimal system was introduced, the day being divided into 10 hours, each hour into 100 minutes, and each minute into 100 seconds. After the lapse of a few years, however, this, together with many other equally absurd innovations, was given up.

The 24 hours into which the day is divided were usually intended to be equal, each comprising $\frac{1}{24}$ part of the whole; but there were exceptions to this. For instance, at one period in the

[a] The old sub-divisions of thirds and fourths have entirely fallen into disuse, every odd part of a second being expressed decimally. Thus: $13^h\ 17^m\ 24^s\ 18^t\ 13^f$ would now be expressed as $13^h\ 17^m\ 24{\cdot}303^s$.

history of Greece the interval between sunrise and sunset was divided into 12 equal portions, termed "hours of the day;" the other interval between sunset and sunrise being also similarly divided into the "hours of the night." It is clear that it is only at the equinoxes that the former would be equal to the latter, that from the vernal to the autumnal equinox the diurnal hours would be the longest, and that during the rest of the year the nocturnal hours would be the longest. A variation in the length of each also took place from day to day. Such a system, inconvenient as it doubtless was for the ordinary affairs of life, was positively useless for all scientific purposes; hence we find that Ptolemy was in the habit of transforming these common hours into equinoctial hours—so called, probably, because at the equinoxes they were equal in duration to the vulgar hour. Even with this improvement we find that that distinguished astronomer was unable to indicate the time of any celestial phenomenon within a quarter of an hour of its true time. This conclusively shews us the imperfections of the chronometric appliances then in use: we are now able to obtain observations within $\frac{1}{10}$ of a second of the absolute truth [b].

Having determined on the unit which we propose to employ as a chronometric register, it is also necessary to determine conventionally some particular moment when each successive unit shall commence and end. The Jews, the Chinese, the ancient Athenians, and Oriental nations, and the Italians in past times, fixed upon sunset as the termination of one day and the commencement of the following, counting the hours from 0 to 24. As the hours of sunrise and sunset vary from day to day, it is manifest that 4 o'clock one day will not be the same as 4 o'clock the day previously; so that for a clock to indicate such time it must be set from day to day, or from week to week, since the hour of sunset will be constantly later during one half year, and

[b] An interesting instance of the surprising accuracy now attainable in astronomical observations was afforded by the occultation of the planet Saturn by the Moon on May 8, 1859. The phenomenon was watched at the Greenwich Observatory by 5 persons, with different telescopes, and the following are the times of disappearance recorded by them:

	h.	m.	s.
Rev. R. Main	8	19	42·4
Mr. Glaisher	8	19	42·5
Mr. Dunkin	8	19	42·6
Mr. Ellis	8	19	42·9
Mr. Criswick	8	19	42·2

Month. Not., vol. xix. p. 238. (May 1859.)

earlier during the other. This system of reckoning has been defended upon the ground of the convenience it affords to travellers and others, in telling them, without trouble, how much time is left at their disposal before nightfall. This is no doubt perfectly correct, as far as it goes; but then, on the other side of the question, the constant necessity of setting the clocks every day has to be considered, to say nothing of the other "obvious inconveniences attending such a system, such as the constant variation of the hours of meals, of going to bed and rising, of all description of regular labour, the hours of opening and closing all public offices, of commencing and terminating all public business," &c. Notwithstanding all this, however, the force of habit is so strong that this system was until lately in use in Italy; though in many places it was customary to set up 2 clocks side by side, one indicating Italian and the other common time. This system, with the unimportant modification of starting from sun*rise*, was also used by the Babylonians, Assyrians, and Persians, and is at the present time adopted by the modern Greeks and the inhabitants of the Balearic Islands. A curious custom of keeping the clocks 1^h in advance of the true time formerly existed at Basle[c].

Hipparchus adopted the plan of commencing the day at midnight, and dividing it into 2 equal series of 12 hours each: this system was followed by Copernicus, and is now in general use throughout all civilised parts of the globe. According to this mode of reckoning, whenever an hour is named, it is requisite to state the position in which it stands as regards noon. The hours previous to noon are indicated by the letters A. M., and those after noon by P. M.—the former being the initial letters of the Latin words *ante meridiem* ("before mid-day"), and the latter of *post meridiem* ("after mid-day"). The ancient Egyptians commenced their day with the Sun's passage over the meridian; in this they were followed by Ptolemy and by astronomers in modern times, who divide the day into 24 hours. In dealing with times mentioned in connection with astronomical matters we must therefore carefully distinguish between civil and astronomical time, the former being 12 hours ahead of the latter.

Days.—A day is the standard unit of measurement now

[c] See Murray's *Handbook for Switzerland*, p. 4.

universally adopted, all shorter intervals of time being reckoned by some of its fractional sub-divisions, and all longer intervals by some or other multiple of it. However, after what has been said in the previous chapter, it is unnecessary to dwell further on the 'day' here.

Weeks.—The historical origin of the well-known period of 7 days is quite lost in antiquity[d], and though some difference of opinion may exist as to the date and prevalence of it as a mode of reckoning, it must undoubtedly be regarded as a memorial of the creation of the world, reference being made to it in the account of that event handed down to us in the Book of *Genesis*. It is also an obvious and convenient subdivision of the lunar month, besides being so nearly an exact aliquot part of a solar year of 365 days ($7 \times 52 = 364$)—two good reasons for its adoption.

The English names of days of the week are derived as follows:—

1.	Dies Solis (Lat.), Sun's day ..	.. whence	Sunday.
2.	Dies Lunæ (Lat.), Moon's day	.. „	Monday.
3.	Tiues daeg (Sax.), Tiu's day ..	.. „	Tuesday.
4.	Wodnes daeg (Sax.), Woden's day	.. „	Wednesday.
5.	Thunres daeg (Sax.), Thor's day	.. „	Thursday.
6.	Friges daeg (Sax.), Friga's day	.. „	Friday.
7.	Dies Saturni (Lat.), Saturn's day	.. „	Saturday.

In many parliamentary and judicial documents the Latin names are still retained; the Quakers, however, do not use either, but call Sunday the 1st day of the week, Monday the 2nd, and so on. The reason why the 1st day of the week is kept as the Christian Sabbath is that the Resurrection of our Lord took place on that day, and it was accordingly determined that the day for the observance of the Sabbath should be changed, to symbolise the displacement of the Primæval by the Christian dispensation, for, be it understood, the principle involved in the Sabbath is the consecration to God of one day in seven, not of any one particular

[d] Laplace's observations on this are very striking, the more so when we consider the times he lived in and the uncertainty that exists as to his religious views:—"The week from the very highest antiquity, in which its origin is lost, has, without interruption, run on through ages, uniting itself with the successive calendars of different nations. . . It is perhaps the most ancient and most incontestable monument of human intelligence, and appears to indicate that all such intelligence came from one common source." (*Exposition du Système du Monde*, vol. i. p. 32.)

day of the week, and this principle dates not from the time of Moses, but from that of Adam.

Dion Cassius (Consul, A. D. 229) ascribes the use of a 7-day period to the Egyptians, and states that from them it was copied in after times by the Greeks and other nations. He makes some curious remarks on the manner in which the Egyptians derived the names of the days of the week and their order from the 7 members of the solar system known to the ancients[e].

The following were the Roman names of the days of the week, the order of sequence being derived from the Egyptians:—

1. Dies Saturni	Saturn's Day.
2. Dies Solis	Sun's Day.
3. Dies Lunæ	Moon's Day.
4. Dies Martis	Mars's Day.
5. Dies Mercurii	Mercury's Day.
6. Dies Jovis	Jupiter's Day.
7. Dies Veneris	Venus's Day.

From the above have been derived the modern names used in the different countries of Europe, either by a literal translation as in the Italian, French, Spanish, and other languages of Latin origin, or, as in the Teutonic languages, by a substitution for the name of the classical, of that of the corresponding Teutonic deity.

Months.—The relation of this division of time to the Moon is singularly apparent in many languages, notwithstanding that the Moon's period of revolution is unsuitable as a measure of time, both on account of its not being marked by any easily-observed phenomena and also because it is not a multiple of either a day or year. The lunar month, however, has been used by the inhabitants of many of the more interesting and important countries of the Earth.

A few memoranda on the months as they now stand may be useful. Every one is familiar with the following lines. I now quote from a version published in 1596:—

"Thirtie daies hath September,
Aprill, June, and November,
Februarie hath eight and twentie alone,
All the rest thirtie and one.
Except in Leap year, at which time
Februarie's daies are twentie and nine."

[e] *Hist. Roman.*, lib. xxxvii. 19.

To find the day of the month without an Almanac, it may be useful to know that except in leap years the following are all of the same name:

1st of January, October.
2nd of April, July.
3rd of September, December.
4th of June.
5th of February, March, November.
6th of August.
7th of May [f].

The common year begins and ends on the same day of the week; leap year ends on the following day. Many persons who speak of the year as consisting of 52 weeks are not aware that it is always 52 weeks 1 day long, and in leap year 52 weeks 2 days long.

A nation possessed of 2 such well-defined chronometric units as the solar day and year would doubtless soon find the inconvenience of not having some period intermediate between them. Let us now see what intermediate subdivisions there are which would answer the purpose. A year does not contain any exact whole number of days—it contains 365¼ (nearly), but since the ancients reckoned it at 365 exactly, we will do the same. Now it is clear that the only factors of 365 are 5 and 73; and we must, therefore, either divide the year into 5 equal periods of 73 days each, or 73 equal periods of 5 days each. That neither of these subdivisions will meet the requirements of mankind we have an intimation in the fact that during more than 5000 years neither of them has ever been adopted. No other equal subdivision of the year being possible, some different plan must be devised; we may either divide the year into a certain number of equal parts, with a remainder, and then consider the remainder as a supplemental part; or we may resolve the year into some convenient number of unequal parts.

The Egyptian year was arranged according to the 1st of these plans, and was divided into 12 months, each of 30 days, with 5 days added at the end of the 12th month.

The Jewish year is regulated according to the 2nd expedient. The following are the months:

[f] A verification of this appears in the *Eng. Cycl.*, art. *Year.*

	Days.		Days.
Tisri	30	Nisan	30
Marchesvan ..	29 or 30	Ijar	29
Kislev	29 or 30	Sivan	30
Tebeth	29	Thamuz	29
Schebat	30	Ab	30
Adar	29	Elul	29 or 30
Veadar (intercalary)	29		

The division of the year into months by the ancient Greeks was not only very unmethodical, but it would seem that no 2 states agreed either in the number, names, or lengths of their months. Some months were designated by particular names, while others were known only by the numerical order in which they followed one another. These numbers, however, did not correspond in different states on account of the year beginning at different times. The confusion arising from such a state of things in a small country, inhabited by one nation speaking one language, may be readily imagined.

Notwithstanding the advanced civilisation of the Romans, it was not till 700 years after the foundation of their city that they became possessed of a properly arranged system of reckoning. The year, as established by Romulus, contained 304 days portioned off into 10 months.

It was soon found that a year of 304 days[g] was irreconcileable with the nature of things; and accordingly we find that in the following reign, that of Numa Pompilius, 2 new months were added, Februarius and Januarius. The latter was placed at the beginning, and the former at the end of the year; this arrangement was however afterwards altered, and Januarius made to precede Februarius, leaving Martius the 1st month of the year. This will account for the fact that September and the 3 following months bear names which do not correspond to the places which they now occupy. In order to make the year correspond with tolerable accuracy to the true solar year, Numa resolved on increasing its length by 51 days, and the months were then arranged as follows:

[g] Sir G. C. Lewis considered this 304-day year to be altogether a myth. *Ast. of Ancients*, p. 56.

	Days.		Days.
Januarius	29	Quinctilis (afterwards Julius)	31
Februarius	28	Sextilis (afterwards Augustus)	29
Martius	31	September	29
Aprilis	29	October	31
Maius	31	November	29
Junius	29	December	29
			355

Januarius derived its name from Janus, the deity who presided over everything. Februarius from Febrius, an ancient Italian deity, whose rites were celebrated this month. Martius from Mars, the god of War, and father of Romulus. Aprilis from Aphrodite. Maius from Maia, the mother of Mercury. Junius from Juno, Queen of Heaven. The names of the months Quinctilis and Sextilis were afterwards changed in compliment to the emperors Julius Cæsar and Augustus Cæsar.

Notwithstanding the modifications introduced by Numa, the year was still 10 days too short; to correct this he decreed that a 13th, or intercalary, month should be introduced every other year, consisting of 22 or 23 days.

The days of the Roman month were reckoned in the following way: the 1st day of each month was called the *kalends*[h]; the 7th day of each of the 4 great months (those of 31 days), and the 5th of each of the lesser months (those of 29 days), were called the *nones;* and the 15th of all the great months, and the 13th of all the lesser months, were called the *ides.* The *nones* were so called as being on the 9th day before the *ides* reckoned inclusively. The word *ides* was derived from the root *id-* which appears in the Latin verb *divido*, and the word signifies the day on which (roughly speaking) the month is divided. The difference in the positions of the two kinds of nones and ides is owing to the Roman custom of reckoning time backwards.

As frequent allusion is made in classical and other writers to the Roman mode of computation, it may be useful to subjoin the following table, shewing the correspondence of the ancient Roman with the modern months:—

[h] This word, not being used by the Greeks, gave rise to the saying, that such and such a thing was postponed to the Greek kalends, or *sine die*, as we should say.

THE ROMAN CALENDAR.

Dies Mensis.	April. Jun. Sept. Nov.	Jan. Aug. Decemb.	Mar. Mai. Jul. Octob.	Feb.
1	Kalendæ.	Kalendæ.	Kalendæ.	Kalendæ.
2	IV.	IV.	VI.	IV.
3	III.	III.	V.	III.
4	Prid. Non.	Prid. Non.	IV.	Prid. Non.
5	Nonæ.	Nonæ.	III.	Nonæ.
6	VIII.	VIII.	Prid. Non.	VIII.
7	VII.	VII.	Nonæ.	VII.
8	VI.	VI.	VIII.	VI.
9	V.	V.	VII.	V.
10	IV.	IV.	VI.	IV.
11	III.	III.	V.	III.
12	Prid. Id.	Prid. Id.	IV.	Prid. Id.
13	Idus.	Idus.	III.	Idus.
14	XVIII.	XIX.	Prid. Id.	XVI.
15	XVII.	XVIII.	Idus.	XV.
16	XVI.	XVII.	XVII.	XIV.
17	XV.	XVI.	XVI.	XIII.
18	XIV.	XV.	XV.	XII.
19	XIII.	XIV.	XIV.	XI.
20	XII.	XIII.	XIII.	X.
21	XI.	XII.	XII.	IX.
22	X.	XI.	XI.	VIII.
23	IX.	X.	X.	VII.
24	VIII.	IX.	IX.	VI.
25	VII.	VIII.	VIII.	V.
26	VI.	VII.	VII.	IV.
27	V.	VI.	VI.	III.
28	IV.	V.	V.	Prid. Kal. Martii.
29	III.	IV.	IV.	
30	Prid. Kal. mensis seq.	III.	III.	
31		Prid. Kal. mensis seq.	Prid. Kal. mensis seq.	

The Mahometan year is a lunar one, consisting of 12 months, of 30 and 29 days alternately, each of which begins with the first

appearance of the New Moon, without any intercalation to bring the year to the same season. It is obvious, therefore, that every year will begin earlier than the preceding one by about 11¼ days. The inconveniences to which this gives rise have already been pointed out. It moreover happens that as the commencement of each month depends on the first visibility of the New Moon, a few cloudy days will produce serious confusion, as it will lead to differences of sometimes a day or two in the reckoning in parts of the country widely separated from each other[i].

One other system may be noticed. In 1792, the French nation, in its excessive desire to sweep away every vestige of monarchy and of the existing institutions of the country, determined on adopting a new calendar, founded on very novel principles; but finding that it was unable to produce any plan more accurate or convenient than the one in previous use, it only made some minor alterations. The first year of the new Republican era commenced on Sept. 22, 1792 (N.S.), the day of the autumnal equinox. The year consisted of 12 months of 30 days each, with 5 supplementary ones kept as festivals. Every 4th year was a leap year, but called by the demagogues a Franciad or Olympic year. The months were as follows[k]:—

Vindemaire	Vintage Month,	commenced	Sept. 22.
Brumaire	Foggy ,,	,,	Oct. 22.
Frimaire	Sleety ,,	,,	Nov. 21.
Nivôse	Snowy ,,	,,	Dec. 21.
Pluviôse	Rainy ,,	,,	Jan. 20.
Ventôse	Windy ,,	,,	Feb. 19.
Germinal	Budding ,,	,,	Mar. 21.
Floréal	Flowering ,,	,,	April 20.
Prairial	Pasture ,,	,,	May 20.
Messidor	Harvest ,,	,,	June 19.
Thermidor	Hot ,,	,,	July 19.
Fructidor	Fruit ,,	,,	Aug. 18.

The Festivals, or *Jours Complémentaires*, were the 5 days from

[i] An exhaustive account of the Mahometan calendar will be found in the *Conn. des Temps*, 1844, p. 111.

[k] An English wag composed the following paraphrase:—

Autumn.—Wheezy, sneezy, breezy;
Winter.—Slippy, drippy, nippy;
Spring.—Showery, flowery, bowery;
Summer.—Hoppy, croppy, poppy.—
Brady, *Clavis Calendaria*, vol. i. p. 38, 2nd ed. 1812.

Sept. 17—21, which were dedicated to "Virtue," "Genius," "Labour," "Opinion," "Reward," respectively.

The bissextile day, intercalated every fourth year, was called *La Jour de la Révolution*, and was set apart for the renewal of the oath to live free or die! Not content to rest here, these misguided men abolished the week, and divided the month into 3 decades, the days of which were named Primidi, Duodi, Tridi, Quartidi, &c.; the 10th, or Decadi, being observed as a sort of Sabbath, though not exactly in a Christian sense of the word! This state of things, as may be supposed, did not last long; "for on Jan. 1, 1806, the Gregorian calendar was resumed, and the Republic, which had legislated for the 4000th year of its existence by name, wore its own livery just one day and a quarter for every one of those years." Fabre D'Eglantine was the author of this calendar.

The whole of the decadery days were kept, or ordered to be kept, as secular festivals. The following is a list of the dedications:—

1. Nature and the Supreme Being.
2. The Human Race.
3. The French People.
4. The Benefactors of Humanity.
5. The Martyrs of Liberty.
6. Liberty and Equality.
7. The Republic.
8. The Liberty of the World.
9. The Love of our Country.
10. The Hatred of Tyrants.
11. Truth.
12. Justice.
13. Chastity.
14. Glory and Immortality.
15. Friendship.
16. Frugality.
17. Courage.
18. Good Faith.
19. Heroism.
20. Disinterestedness.
21. Stoicism.
22. Love.
23. Conjugal Faith.
24. Parental Love.
25. Maternal Tenderness.
26. Filial Piety.
27. Infancy.
28. Youth.
29. Manhood.
30. Old Age.
31. Misfortune.
32. Agriculture.
33. Industry.
34. Our Ancestors.
35. Posterity.
36. Prosperity.

"That one day in the calendar should have been appropriated to the '*Supreme Being*' *in conjunction with* '*Nature*' was a low conceit of Robespierre, who meant to identify Nature with the Supreme Being as one and the same source; and yet even this slight remembrance of the Almighty power appears to have

afforded some consolation to a great majority of the people who had not lost every sense of religion; and to delude them with a belief of his sincerity, that arch-hypocrite himself joined in apparent devotion to *that* Almighty power whose attributes it was his real object to deride. He had even the audacious craft to decree a *fête* for the express purpose of paying *adoration* to the Deity, when for *one* day the fatal guillotine was veiled from public view; and the better to conceal his depravity, a hideous and frightful figure, prepared for public exhibition at the festival, as the type of atheism, was previously destroyed. Part of the community, after these regulations, distinguished *Sunday* in the ancient style of festivity, whereby to *mark* the recurrence of that holy day, though no one had the temerity publicly to oppose the current of error by a more suitable observance. Many, indeed, wholly conformed to the innovation, and hence one part of the people shut up their shops on Sundays, while the *sans culotte* adherents of Robespierre rigidly observed the decades[1]." Robespierre artfully overcame the difficulty by decreeing that both the Sundays and the decades should be observed as festivals, thus granting to the people 88 days of recreation in the year instead of 36 or 52.

The year is the largest astronomical chronometric unit, and is used to express all long periods of time. It is, as I have already shewn, in some form or other a derivative of the Earth's revolution round the Sun, in connection with the Moon's revolution round the Earth. Various times have been used to fix the commencement of the year; we now call Jan. 1, New Year's Day, though previous to the introduction of the new style of reckoning in 1752, the 25th of March was usually considered the 1st day of the new year. On referring to the Anglican Book of Common Prayer, it will be seen that the ecclesiastical year begins on Advent Sunday, whilst the academical year used at the Universities begins in October. Dec. 25, March 1, Easter Day, Sept. 22, &c., have all been used at different times for the same purpose.

The year is also subdivided into 4 quarters, which point out the days on which the Sun attains its greatest Declination, North or South (called the solstices, summer and winter), and on which

[1] Brady, *Clavis Calend.*, vol. i. p. 35.

it is on the equator going North or South (called the equinoxes, vernal or autumnal). Owing to physical causes (already considered in Book III, *ante*), these events do not now take place at equal intervals, and will not do so for several thousand years to come. The following are the dates of the commencement of the seasons, and their lengths, in 1860:—

		d.	h.	m.		d.	h.	m.	
Spring commences	Mar.	19	21	5	.. ..	92	20	38	length of Spring.
Summer „	June	20	17	43	.. ..	93	14	9	length of Summer.
Autumn „	Sept.	22	7	52	.. ..	89	17	59	length of Autumn.
Winter „	Dec.	21	1	51	.. ..	89	1	2	length of Winter.
						365	5	48	

The following days of the year are used as quarter-days, for leases, &c., in England and Scotland:—

England.	Scotland.
March 25, or Lady-day.	Feb. 2, or Candlemas-day[m].
June 24, or Midsummer-day.	May 15, or Whitsun-day.
Sept. 29, or Michaelmas-day.	Aug. 1, or Lammas-day[m].
Dec. 25, or Christmas-day.	Nov. 11, or Martinmas-day.

[m] These are also used in several parts of England.

CHAPTER III.

Means of measuring Time.—The Almanac.—Epitome of its contents.—Times of Sun-rise and Sunset.—Positions of the Sun, Moon, and Planets.—The Phases of the Moon.—The Ecclesiastical Calendar.—The Festival of Easter.—Method of calculating it.

NATURE, though she has supplied us with visible phenomena to measure the larger units of time, such as days, months, and years, has not furnished us with any means whereby we may measure the lesser units of hours, minutes, and seconds; artificial contrivances must therefore be sought for. Rough approximations to the true time were at first obtained by setting up *gnomons*, or upright staves [a]; which, in conjunction with a knowledge of the North point of the heavens, would afford a tolerably correct indication of noon, or the moment of the Sun's passage over the meridian. An instrument constructed with a gnomon pointing towards the North Pole of the heavens constitutes a *sun-dial*, and affords a still better mode of ascertaining the hour of the day [b]. According to Herodotus, sun-dials were first introduced into Greece from Chaldæa; the hemisphere of Berosus, who lived 540 B.C., is the oldest recorded in history [c].

The earliest attempt to form a strictly artificial time-keeper is due to Ctesibius, of Alexandria [d] (about 250 B.C.), who invented *clepsydræ*, or water-clocks, which were contrivances for allowing

[a] Ptolemy describes one erected at Alexandria. (*Almag.*, lib. iii. cap. 2.)

[b] A very clear outline of the subject of *Dialling* (*i.e.* the construction of Sun-dials) will be found in Lockyer's *Elementary Astronomy*, chap. v.

[c] Described by Vitruvius, *De Architecturâ*, lib. ix. cap. 9. Stuart mentions one found on the south side of the Acropolis at Athens, which is probably of the same kind as the above. (*Antiquities of Athens*, vol. ii.)

[d] Vitruvius, in loc. cit.

a continuous stream of water to trickle through a small aperture in the pipe of a funnel, the time being measured by the quantity of fluid discharged. A species of clepsydra, in which mercury is employed, was introduced with great success by the late Captain Kater for the measurement of minute intervals of time by persons engaged in delicate philosophical experiments. *Sand-glasses*, still used for boiling eggs, and in the Houses of Parliament to fix the termination of the time allotted to members to prepare for a Division, are merely small clepsydræ in which sand is used instead of water.

All the above contrivances have now, more or less, fallen into disuse, being supplanted by the pendulum clock and the watch—into a description of which it would be foreign to my present purpose to enter.

Of all secular books to be found in every library, however humble, there is none of such indispensable value as the Almanac[e]. One might imagine that a book so generally used by everybody would be fully understood by all; but this is by no means the case, and there are probably few things about which so much ignorance prevails, notwithstanding the frequency with which the Almanac is consulted.

The word "Almanac" (the derivation of which is uncertain[f]) is applied to publications which describe the astronomical, civil, and ecclesiastical phenomena of the year. The word "Calendar," applied, in a more limited sense, to the events of the several months, comes from the Greek *καλέω*, I summon.

The astronomical phenomena which usually find a place in good Almanacs are the following:—(1) The times of Sunrise and Sunset; (2) the Right Ascension and Declination of the Sun, Moon, and principal planets; (3) the Equation of Time; (4) the times of High and Low Water; (5) the times of rising, meridian passage, and setting of the Moon; (6) the Moon's phases and age; concerning each of which a few words will here be said.

(1) If the Earth's axis were perpendicular to the plane of the ecliptic, the Sun would always (as at the equator) rise in the East

[e] Much useful information about Almanacs and time generally will be found in Chambers's *Book of Days*, vol. i. p. 1.

[f] Arago gives as the derivation, *man*, the Moon. (*Pop. Ast.*, vol. ii. p. 721, Eng. ed.)

and set in the West; but as it is inclined at an angle of 66° 32′ 32″, this is not the case: and it is this inclination which gives rise to the alternation of the seasons and the ever-varying length of each successive day. It also follows from this that the hour at which the heavenly bodies rise, culminate, and set, differs on the same day at places having different latitudes or different longitudes. Celestial objects which will be visible from one place will be invisible from another. Thus the constellation of the Great Bear, which we see in England, is invisible at the Cape of Good Hope; and, conversely, the Southern Cross, which glitters in the other hemisphere, is never seen so far North as England: so that spectators in Northern latitudes look *down* at objects which spectators in Southern latitudes look *up* at, and which spectators in the Tropics see *directly over* their heads.

These circumstances must be borne in mind when we propose to ascertain beforehand the aspect of the heavens at any particular place, on any given night. From observation and theory we learn that the aspect of the heavens changes from hour to hour; and, knowing the period occupied by the Earth in her diurnal rotation and annual revolution, it becomes an easy matter to foretell, by calculation, what celestial objects will be visible at any proposed day and hour. The presence of an atmosphere around the Earth gives rise to the phenomenon of refraction[g], by which the heavenly bodies, when near the horizon, suffer a considerable displacement, equal to about 33′ (at the horizon), by which quantity the apparent exceeds the true altitude. Now since the diameter of the Sun is only 32′, it follows that the Sun is elevated through a space equal to more than its own diameter; so that when we see the disc of the Sun apparently just above the horizon, the Sun itself is, in reality, just below it; and would therefore, were it not for the atmosphere, be invisible. The time of *apparent* sunrise and sunset is what is now given in our Almanacs. It is at the equinoxes only that the interval between sunrise and sunset is equal to the interval between sunset and sunrise, or that the length of the day is equal to the length of the night[h]: this occurred on March 20 and Sept. 23 in the year 1875.

[g] See p. 272, *ante*.
[h] This is not strictly true, but I use the term in a popular sense.

By reason of the fact that Civil reckoning divides the day (of 24 hours) into 2 equal portions of 12 hours each, counted from midnight and from mid-day, a knowledge of the time of sunrise or sunset will furnish a promptly available means of determining approximately the length of the night or length of the day respectively. For instance, if the Sun rises at 5.0 A.M., 5 hours have elapsed since the previous midnight; but midnight is the mid-interval between sunset and sunrise: therefore the night is $5 \times 2 = 10$ hours long. In the same way, if the Sun sets at 7.0 P.M., the day is $7 \times 2 = 14$ hours long. Thus we arrive at 2 useful rules:—(i) *Twice the time of sunset = the length of the day:* (ii) *Twice the time of sunrise = the length of the night.*

(2) The Right Ascension (R.A.) of a celestial object is its distance, reckoned on the equator, from the vernal equinox, or first point of Aries, either in angular measure, of degrees, minutes, and seconds ($^{\circ}\ '\ ''$); or in time, of hours, minutes, and seconds ($^{h\ m\ s}$)—24 hours making a circumference of a circle; each hour, therefore, being equal to 15° of arc. The Declination (δ) is the angular distance of a celestial object from the equator reckoned North (+), or South (−), towards the Poles. Sometimes the position of an object is indicated by its angular distance being reckoned from the North down to the South Pole: when this is the case it is indicated by the abbreviation N.P.D.—North Polar Distance.

(3) The Equation of Time has already been explained.

(4) The times of High and Low Water are usually given for the port of London; an additional constant, called the ***Establishment***, being supplied, by means of which tidal phenomena at all the other ports given in the list can be readily ascertained.

(5) When the Moon, in the course of her revolution round the Earth, has the same Longitude as, and passes the meridian with, the Sun, it is said to be in *conjunction* (☌), or to be "New" (●). We know that the Moon completes a synodic revolution in $29^{d}\ 12^{h}\ 44^{m}\ 2{\cdot}873^{s}$. It therefore moves round the heavens, from West to East, at the rate of $13^{\circ}\ 10'\ 35''$ ($13{\cdot}1764^{\circ}$) daily; while the Sun moves in the same direction, with a mean daily motion of $59'\ 8{\cdot}3''$: the Moon, therefore, departs Eastward from the Sun $12^{\circ}\ 11'\ 27''$ every 24 hours. On the 8th day, or about a week after conjunction, it will be 90° from the Sun. This

phase is the *maximum elongation East*, or *Eastern quadrature* (E. □), and is popularly known as the "First quarter" (☽). The Moon, previously a crescent, is then halved, with its illuminated limb turned towards the Sun. Proceeding onwards, it becomes gibbous, and about 14 days from conjunction attains an angular distance of 180° from the Sun. It is then in *opposition* to the Sun (☍), and the Moon is said to be "Full" (○). At the end of another period of 7 days, or 21 from conjunction, the Moon, after becoming gibbous, is again halved; but it is the opposite limb which is now illuminated. This phase is the *maximum elongation West*, or *Western quadrature* (W. □), and is popularly known as the "Last quarter" (☾). Finally, after the lapse of another 7 days, the Moon again comes into conjunction.

In nearly every Almanac there is a column assigned to the "Moon's age." This is simply the interval in days and parts of a day which have elapsed since the Moon's last conjunction with the Sun. Thus, on Friday, January 1, 1875, we find that at noon the Moon's age was $23{\cdot}5^{d}$: this means that 23·5 days had elapsed since the last previous conjunction on Dec. 8, 1874. An examination of the dates of several successive New Moons will shew that the lengths of different lunations differ considerably, owing to the varying velocity of the Moon's orbital motion: this is due to numerous and complicated physical causes, which cannot be conveniently examined here. In associating any lunation with any particular month, it may be well to mention that the Moon does not take its name from the month in which it passes the principal part of its time, but from the one in which the lunation terminates. Thus, in the year 1875, the "September Moon" is that which commenced on August 30, and terminated on September 29. All writers on chronology agree in this arrangement, which is sometimes attended with rather absurd consequences. There were, in fact, in 1875, two "August Moons;" the whole of the first, however, with the exception of 13^{h}, belonging to the month of July. Since the month of February in a common year only contains 28 days, and a lunar month always exceeds 29 days, it will sometimes happen that there will be no "February Moon" at all.

It is not necessary to advert to the civil portion of the Calendar further than to mention that Quarter-days, Law and University

Term-days, and anniversaries of important by-gone events, &c., all find a place in every well-edited Almanac.

The Ecclesiastical Calendar has for its object the regulation of the different Sundays and festivals ordained by the Church to be kept holy. Some religious festivals—such as the Feast of St. Andrew, the Nativity of our Lord, the Annunciation of the Blessed Virgin, &c.—are observed on the same day of the month every year; others, such as Easter, return on different days in different years, whence they are termed *Moveable Festivals*. Easter is the most important of all, for upon this depend nearly all the rest.

The Jewish Feast of the Passover was observed in accordance with the following commands:—"In the 1st month, on the 14th day of the month at even, ye shall eat unleavened bread, until the 21st day of the month at even." (*Exodus*, xii. 18.) Again:—"In the 14th day of the 1st month at even, is the Lord's Passover." (*Leviticus*, xxiii. 5.) And since our Saviour was crucified at the time of the Jewish Passover, our festival of Easter has ever been a moveable one. The word 'Easter' is probably of Saxon origin, for the ancient Saxons sacrificed in the month of April to a goddess whom they called Eoster (in Greek *Astarte*, and in Hebrew *Ashtaroth*[1]), whose name was given to the month in question. It has been suggested that the word *East* in Saxon refers to "rising," and that the point of the compass now known by that name derived it from the rising of the Sun, and the festival from the rising of our Saviour. Another derivation is the Saxon *yst*, a storm, on account of the tempestuous weather which frequently prevails at this season of the year. That the observance of Easter as a Christian institution is as ancient as the times of the Apostles there can be no doubt; but in the 2nd century a controversy arose as to the exact time at which it ought to be celebrated. The Eastern Church elected to keep it on the 14th day of the 1st Jewish month; and the Western on the night which preceded the anniversary of our Saviour's Resurrection. The objection to the former plan was, that the festival was commonly held on some other day than the 1st day of the week,

[1] *Vide* Milton, *Paradise Lost*, bk. i. l. 438, where it is referred to as a Phœnician deity.

which was undoubtedly the proper one. The disputing Churches each had their own way until 325 A.D., when the Council of Nicæa took up the matter, and eventually it came to be recognised that Easter was to *be kept on the Sunday which falls next after the first Full Moon following the 21st of March, the vernal equinox. If a Full Moon fall* on *the 21st of March, then the next Full Moon is the Paschal Moon; and if the Paschal Moon fall* on *a Sunday, then the next Sunday is Easter Day.*

By common consent, it is not the apparent or real Sun and Moon which is employed in finding Easter, but the mean or fictitious sun and moon of astronomers. We must, therefore, not be surprised at finding sometimes the Easter of any year not agreeing with the above definition. Such was the case in 1845 and in 1818, when violent controversies took place about it. Suppose, for instance, that the real opposition of the Sun and Moon took place at $11^h\ 59^m$ P.M., March 21, and the mean opposition 2^m afterwards. It is clear that, counting by the real bodies, the Full Moon in question would not be the Paschal Moon, while that of the mean bodies would be so[k]. However, the following rules will determine the Easter Day of chronologists for any year of the Christian era, and this is all that is necessary[l]:—

I. Add 1 to the given year.
II. Take the quotient of the given year, divided by 4, neglecting the remainder.
III. Take 16 from the centurial figure of the given year if it can be done.
IV. Take the remainder of III, divided by 4, neglecting the remainder.
V. From the sum of I, II, and IV, subtract III.
VI. Find the remainder of V, divided by 7.
VII. Subtract VI from 7: this is the number of the DOMINICAL LETTER.

A	B	C	D	E	F	G
1	2	3	4	5	6	7

VIII. Divide I by 19: the remainder (or 19 if there is no remainder) is the GOLDEN NUMBER.
IX. From the centurial figures of the year subtract 17, divide by 25, and keep the quotient.
X. Subtract IX and 15 from the centurial figures, divide by 3, and keep the quotient.
XI. To VIII add 10 times the next less number, divide by 30, and keep the remainder.

[k] The investigation of this question is too long and complicated to interest the general reader. Those who wish for it will find it in a valuable memoir, by Prof. De Morgan, in the *Companion to the Almanac* for 1845, p. 1.

[l] Gauss's method is a very good one.

XII. To XI add X and IV, and take away III, throwing out the thirties, if any. If this gives 24, change it into 25. If 25, change it into 26, whenever the Golden Number exceeds 11. If 0, change it into 30. Thus we get the Epact.

When the Epact is 23 or less.	*When the Epact is greater than 23.*
XIII. Subtract XII from 45.	XIII. Subtract XII from 75.
XIV. Subtract the Epact from 27, divide by 7, and *keep the remainder*.	XIV. Subtract the Epact from 57, divide by 7, and *keep the remainder*.

XV. To XIII add VII (and 7 besides, if XIV be greater than VII) and subtract XIV, the result is the day of March, or, if more than 31, subtract 31, and the result is the day of April on which Easter day falls.

The following exemplifies the above rule:—

To find when Easter falls in 1880.

I. $1880 + 1 = 1881$.

II. $\dfrac{1880}{4} = 470$: 0 rem.

III. $18 - 16 = 2$.

IV. $\dfrac{2}{4} = 0$: 2 rem.

V. $1881 + 470 + 0 - 2 = 2349$.

VI. $\dfrac{2349}{7} = 335$: 4 rem.

VII. $7 - 4 = 3$: whence C is the Dominical Letter.

VIII. $\dfrac{1881}{19} = 99$: 0 rem. $\therefore$ 19 is the Golden Number.

IX. $\dfrac{18 - 17}{25} = 0$: 1 rem.

X. $\dfrac{18 - (0 + 15)}{3} = 1$.

XI. $\dfrac{19 + 180}{30} = 6$: 19 rem.

XII. $19 + 1 + 0 - 2 = 18$: which is the Epact.

XIII. $45 - 18 = 27$.

XIV. $\dfrac{27 - 18}{7} = 1$: 2 rem.

XV. $27 + 3 - 2 = 28$; so March 28 is Easter Day.

Easter Day being known, any of the other days depending on it can readily be found.

Septuagesima Sunday is 9 weeks
Sexagesima Sunday is 8 weeks
Shrove or *Quinquagesima Sunday* is 7 weeks
Shrove Tuesday and *Ash Wednesday* follow *Quinquagesima Sunday*
Quadragesima Sunday is 6 weeks
Palm Sunday is 1 week
Good Friday is 2 days
} Before Easter.

Low Sunday is 1 week
Rogation Sunday is 5 weeks
Ascension Day, or *Holy Thursday*, follows *Rogation Sunday*
Whitsun-Day is 7 weeks
Trinity Sunday is 8 weeks
} After Easter.

On the subject of the calculation of Easter, and indeed of the Calendar generally, see the works named in the note[m].

[m] *English. Cycl.*, various articles; Beckett's *Astronomy without Mathematics*, chap. iii; De Morgan's *Book of Almanacs; Companion to the Almanac*, 1845; Rees's *Cycl.*; J. J. Bond's *Perpetual Calendar*.

CHAPTER IV.

The Dominical or Sunday Letter.—Method of finding it.—Its use.—The Lunar or Metonic Cycle.—The Golden Number.—The Epact.—The Solar Cycle.—The Indiction.—The Dionysian period.—The Julian period.

THE *Dominical Letter*, called also the Sunday Letter, is an expedient by means of which we can readily find out the day of the week on which any day of the year falls, if we know the day of the week on which New Year's Day falls. To the first 7 days of January are affixed the first 7 letters of the alphabet—A, B, C, D, E, F, G; and of these, that which denotes Sunday is the Dominical Letter. Thus, if Sunday is New Year's Day, then A is the Dominical Letter; if Monday, that letter is G; and so on. If there were 364 days, or 52 weeks, exactly in the year, then the Dominical Letter would always be the same; but as the year contains about 365¼ days, or 1¼ more than 364, this excess has to be taken into account every year, and the ¼ makes a day in every 4 years; so that the Dominical Letter falls backward *one* letter every common year, and *two* letters every Bissextile or Leap year. Knowing the Dominical Letter, we can ascertain all the Sundays, or all the Mondays, &c., in the year. The reason why Leap years have 2 letters may be thus explained:—Take, for example, the year 1880. The year begins on a Thursday, so that D is the Sunday Letter; but the intercalary day, February 29, throws back the 1st of March a day later than it would otherwise have been, and therefore the Sunday Letter for the following 10 months is thrown back 1—that is to say, to C; so that the Dominical Letters for 1880 are D and C. The following examples, worked according to the 1st part of the rule already given to find Easter, illustrate the practical use of a knowledge of the Dominical Letter:—

1. What day of the week is June 4, 4779?

I. $4779 + 1 = 4780.$

II. $\frac{4779}{4} = 1194$: 3 rem.

III. $47 - 16 = 31.$

IV. $\frac{31}{4} = 7$: 3 rem.

V. $4780 + 1194 + 7 - 31 = 5950.$

VI. $\frac{5950}{7} = 850$: 0 rem.

VII. $7 - 0 = 7$. ∴ G is the Dom. Letter.

Now June 3 has G affixed to it, and is Sunday; whence June 4, 4779, will fall on a Monday.

2. What is the 1st Sunday in June, 1880?

I. $1880 + 1 = 1881.$

II. $\frac{1880}{4} = 470$: 0 rem.

III. $18 - 16 = 2.$

IV. $\frac{2}{4} = 0$: 2 rem.

V. $1881 + 470 + 0 - 2 = 2349.$

VI. $\frac{2349}{7} = 335$: 4 rem.

VII. $7 - 4 = 3$. ∴ C is the Dom. Letter.

Now June 6 has C affixed to it, so that day is the 1st Sunday in June in 1880.

Since the Solar year consists of $365^d\ 5^h\ 48^m\ 48^s$, therefore 19 Solar years will consist of about—

$$6939^d\ 14^h\ 27^m\ 12^s;$$

and since the mean duration of a Lunar month is $29^d\ 12^h\ 44^m\ 3^s$, therefore 235 mean Lunar months will consist of about—

$$6939^d\ 16^h\ 31^m\ 45^s.$$

Thus we see that 19 Solar years fall short of 235 Lunar months by only $2^h\ 4^m\ 33^s$; if, therefore, any given length of time be resolved into periods of 19 years each, the same phases of the Moon which are presented in any year of one cycle will be reproduced in the corresponding year of the following cycle, but $2^h\ 4^m\ 33^s$ later. If we reckoned time by Solar years, and if the length of each lunation were always $29^d\ 12^h\ 44^m\ 3^s$, the days of the Moon's changes in any one cycle being known, the days of the Moon's changes in every succeeding and every preceding cycle could be easily ascertained. But since the Solar year of $365^d\ 5^h\ 48^m\ 48^s$ is not employed, and the duration of different lunations varies,

the reproduction of Lunar phases on corresponding days does not take place.

"Unlike the Astronomical year [Solar], the Civil year is not constantly of the same length. It consists, as has been already explained, sometimes of 365 and sometimes of 366 days. Neither is a cycle of 19 successive Civil years always of the same length. Such a cycle contains sometimes only 5 and sometimes 4 Leap years, and consists, therefore, sometimes of 6940 and sometimes of 6939 days. It, therefore, sometimes exceeds a cycle of 19 Astronomical years by nearly ¼ day, and sometimes falls short of such a cycle by more than three-quarters of a day. If 4 successive cycles of 19 Civil years be taken, 3 of them will exceed 1 Astronomical year by something less than ¼ day, and the 4th will fall short of an Astronomical year by something more than ¾ day. The total length of the 4 successive cycles of 19 Civil years will be as nearly as possible equal to 4 cycles of 19 Astronomical years [a].

"Thus it is evident that the Civil year, though variable in length, oscillates alternately on one side and the other of the Astronomical year; and, in like manner, the cycle of 19 Civil years, which is also variable by 1 day, oscillates at each side of the cycle of 19 Astronomical years. The Civil year and the Civil cycle are alternately overtaking and overtaken by the Astronomical year and cycle, and their average lengths are respectively equal in the long run to the average length of the latter. In like manner the Lunar month is subject to a certain limited variation; so that the phases of the real Moon are alternately overtaking and overtaken by those of the average moon.

"Now, let us imagine a fictitious moon to move round the heavens in the path of the real Moon, but with such a motion that its periodical phases shall take place in exact accordance with the Civil years, and with the cycles of 19 Civil years, in the same manner as the phases of the real Moon recur in the succession of Astronomical years, and in the cycles of 19 Astronomical years. Such a fictitious moon is then the Ecclesiastical Moon, and is the moon whose phases are predicted in the Calendar. It will be

[a] This cycle of 76 years (19 × 4) is known as the *Calippic period*, from Calippus who first drew attention to it. The paragraph in the text and the two following ones are from the *Museum of Science and Art*, vol. vii. p. 13.

evident from all that has been explained that this Ecclesiastical Moon will alternately pursue, overtake, and outstrip the real Moon, and be pursued, overtaken, and outstripped by it; that they will thus make together their successive revolutions of the heavens, and that they will never part company, nor either outstrip or fall behind the other beyond a certain distance, which is limited by the extent of the departure of the Civil from the Astronomical year, and by that of the real from the average Lunar Month."

The course of time is now considered to be made up of so many cycles each of 19 Civil years; and it has been agreed that each cycle shall commence with a year, the 1st day of which shall be the last of the preceding lunation, or the day on which the age of the following Moon is 0. The number which marks the place of any given year in the cycle is termed the *Golden Number*, and the period the *Lunar* or *Metonic Cycle,* from its discoverer, Meton. When the discovery of this cycle was first published, so great was the popular favour which was bestowed upon it, that it was ordered to be written up in letters of gold[b]. The age of the Ecclesiastical Moon on the 1st day of the 1st year of the cycle being known, its age upon the 1st day of any succeeding year of the cycle may be determined. The number which expresses the age of the Moon upon the 1st day of any year of the cycle is called the *Epact.* The series of Epacts corresponding to the years of a Lunar cycle are given in the following table:—

Year of Cycle	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Epact	0	11	22	3	14	25	6	17	28	9	20	1	12	23	4	15	26	7	18

The method of finding the Golden number and Epact for any given year has already been shewn in the rule for finding Easter.

The *Solar Cycle* is the period of years that elapses before the days of the week correspond to the same days of the month. If there were 364 days in the year, this would happen every year; if 365, it would happen every 7th year: but because the ¼ of a day makes an alteration of a whole day in 4 years, the cycle must extend to 7 × 4, or 28 years. Nine years of this cycle had elapsed at the birth of Christ. Therefore, *to find the cycle of the*

[b] The Metonic Cycle was adopted on July 16, 432 B.C., and the New Moon, which happened at 7h 43m P.M., was the actual commencement of it.

Sun, add 9 to the given year, and divide by 28, and the quotient will be the number of cycles since the commencement of the Christian Era, and the remainder is the cycle of the Sun.

Example. To find the Cycle of the Sun for 1880:—

$$\text{I.}\quad 1880 + 9 = 1889.$$

$$\text{II.}\quad \frac{1889}{28} = 67 : 13 \text{ rem.};$$

whence 13 is the number in the Solar Cycle for the given year.

The cycle of the *Indiction* has no immediate connexion with the motions of the Sun and Moon, but it may, however, as well be referred to here. It is a period of 15 years, first established as a conventional division of time in the Roman empire by the Emperor Constantine. It has been conjectured, though Arago considers the notion baseless, that it was designed to supersede the Pagan method of reckoning time by Olympiads—periods of 4 years, familiar to every classical reader. Unlike the Golden number and the Epact, the Indiction was purely a Civil period. Gregory VII finally fixed upon the 1st day of the year 313 A.D. as the commencement of the Indiction, whence it follows that the 1st year of the Christian era was the 4th of the current Indiction. *To find the Indiction, add 3 to the given year, and divide by 15, and the remainder will be the Indiction.*

Example. To find the Indiction for 1880:—

$$\text{I.}\quad 1880 + 3 = 1883.$$

$$\text{II.}\quad \frac{1883}{15} = 125 : 8 \text{ rem.};$$

whence 8 is the Indiction of the given year.

The *Dionysian Period* is obtained by a combination of the Lunar and Solar cycles, forming a period of 532 years ($19 \times 28 = 532$); at the end of which time the changes of the Moon take place on the same days of the week and month as before. This period is said to be valuable for testing the accuracy of chronological statements.

The *Julian Period*, a period useful in chronology, is obtained by multiplying together the Lunar cycle, the Solar cycle, and the Indiction, forming a period of 7980 years—

$$(19 \times 28 \times 15 = 7980.)$$

"The number 7980 is formed by the continual multiplication of the 3 numbers 28, 19, and 15: that is of the cycle of the Sun, the

cycle of the Moon, and the cycle of Indiction. The 1st year of the Christian Era had 10 for its number in the cycle of the Sun, 2 in the cycle of the Moon, and 4 in the Indiction. Now the only number less than 7980 which on being divided successively by 28, 19, and 15, leaves the respective remainders 10, 2, and 4, is 4714. Hence the 1st year of the Christian Era corresponded with 4714 of the Julian period[c]." The 1st year of the Julian Period was therefore 4713 B.C. It was Scaliger who propounded this period[d].

This will be a convenient place to mention that for dates before the Christian Era astronomers adopt a method of reckoning differing from that used by chronologists. Thus 584 B.C. astronomical reckoning, corresponds to 585 B.C. chronological reckoning[e]. Sometimes astronomical dates of events happening before the birth of our SAVIOUR are given in this form: (−584), as being, in some sense, negative quantities. In comparing, or, generally, in dealing with, dates antecedent to the Christian Era, due attention to these distinctions is of prime importance.

[c] Brande's *Dictionary*, art. *Julian Period*.

[d] The standard work on chronology is Ideler's *Handbuch der mathematischen und technischen Chronologie*. Eras and epochs are treated of at length by De Morgan in the *Companion to the Almanac*, 1850, p. 5.

[e] The cause of this will be seen from the following table of the respective methods of progression:—

Astronomical.		*Chronological.*
3 B.C.	=	4 B.C.
2 B.C.	=	3 B.C.
1 B.C.	=	2 B.C.
0	=	1 B.C.
1 A.D.	=	1 A.D.
2 A.D.	=	2 A.D.
3 A.D.	=	3 A.D.

BOOK VI.

THE STARRY HEAVENS.

CHAPTER I.

INTRODUCTION.

"O ye Stars of Heaven, bless ye the LORD: praise Him, and magnify Him for ever."—*Benedicite.*

The Pole-Star.—Not always the same.—Curious circumstance connected with the Pyramids of Egypt.—Stars classified into different magnitudes.—Antiquity of the custom of forming them into groups.—Anomalies of the present system.—Stellar photometry.—Distances of the Stars.—How distinguished.—Antiquity of the custom of naming Stars.—Invention of the Zodiac.—Letters introduced by Bayer.—Effects of the increased care bestowed on observations of the Stars.—Ideas of the Ancients respecting the Stars.—Remarks by Sir J. Herschel.

IF, on some clear evening, the reader will go out into the open air, and station himself preferably (if that be possible) on the summit of any rising ground and look upwards, he will see the sky spangled with multitudes of brilliant specks of light; these are the *fixed stars*, so called, but we shall presently see that this appellation is not strictly correct. An attentive observer will soon notice, also, that the stars which he is contemplating seem to revolve in a body around one situated in the North, about (in England) midway between the horizon and the zenith; this is the Pole-star, so designated from its being near the Pole of the celestial equator. Owing, however, to the *precession of the equinoxes*[a], the present Pole-star (α Ursæ Minoris) will not always be such; the true Pole is now about $1\frac{1}{2}°$ from this star, and this distance will gradually

[a] See Book III (*ante*).

diminish until it is reduced to about $\frac{1}{2}°$; it will then increase again, and after the lapse of a long period of time, the Pole will depart from this star, which will then cease to bear the name of, or serve the purposes of, a Pole-star. About 4600 years ago the star *a* Draconis fulfilled this office; 12,000 years hence, it will fall to the lot of *a* Lyræ, a brilliant star of the 1st magnitude, which is now 51° 20′ from the Pole, but which will then have approached to within less than 5° of the polar point[b].

Connected with this subject a curious circumstance was noticed in the researches which were made in Egypt some years ago by Col. Vyse. Of the 9 pyramids which still remain standing at Gizeh, 6 have openings which face the North, leading to straight passages, which descend at inclinations varying from about 26° to 28°, the direction of these passages being, in all cases, parallel to the meridian. Now if we suppose a person to be standing at the bottom of any one of these passages, and to look up it, as he would through the tube of a telescope, his eye will be directed to a point on the meridian 26° or 28° above the plane of the horizon. The altitude at which the star *a* Draconis must have passed the lower meridian, at the place in question, 4000 years before the present time, is $26\frac{1}{2}°$. Now the present age of these pyramids (the great pyramid bears the date of 2123 B.C.) corresponds so nearly with this period ($2123+1876=3999$), that it can hardly be doubted that the peculiar direction given to these passages must have had reference to the position of *a* Draconis, the then Pole-star[c]. C. P. Smyth however, pointing out the fact that the lower culmination of *a* Draconis alone would be recognised by this arrangement, and thinking that something connected with an upper culmination should assuredly be looked for, finds that something in the Pleiades, which would at the epoch alluded to culminate above the pole coincidently with *a* Draconis below; and he considers moreover that the 7 chambers of the great pyramid commemorate the 7 Pleiads.

The stars, on account of their various degrees of brilliancy, have been distributed into classes or orders. Those which appear

[b] For a list of possible Pole-stars between 4800 B.C. and 13800 A.D. see a paper in *Ast. Reg.*, vol. viii. p. 244. Nov. 1870.

[c] *Phil. Mag.*, vol. xxiv. pp. 481-4. June 1844. Pytheas of Marseilles, 330 B.C., was the first to notice that the so-called Pole-star was not situated exactly at the Pole.

largest are called stars of the 1st magnitude; next to these come stars of the 2nd magnitude; and so on to the 6th, which are the smallest visible to the naked eye. This classification having been made long before the invention of telescopes, those stars which cannot be seen without the assistance of such instruments are called *telescopic*, and are classed in magnitudes varying from the 7th to the 18th or 20th; these latter, of course, being only visible in the most powerful instruments hitherto constructed; nor does it seem reasonable to assign a limit to this progressive diminution, inasmuch as past experience has shewn that every successive improvement in the construction of telescopes brings to light new objects, previously unknown because small and faint.

Some astronomers, when they wish to signify that a star occupies an intermediate place between 2 magnitudes, mark it thus:— 1·2: or thus:— 2·1. These dots are not intended to be decimal points, but mean that the star is below the 1st and above the 2nd magnitude; in the former case nearer the 1st than the 2nd, in the latter nearer the 2nd than the 1st. This is a very clumsy system, and its continuance is to be deprecated.

It may be worth while here to give a list of the stars of the 1st magnitude arranged as near as may be in the order of brightness:—

α Canis Majoris. (Sirius.)	α Tauri. (Aldebaran.)
α Argûs. (Canopus.)	β Centauri.
α Centauri.	α Crucis.
α Boötis. (Arcturus.)	α Scorpii. (Antares.)
β Orionis. (Rigel.)	α Aquilæ. (Altair.)
α Aurigæ. (Capella.)	α Virginis. (Spica.)
α Lyræ. (Vega.)	α Piscis Australis. (Fomalhaut.)
α Canis Minoris. (Procyon.)	β Crucis.
α Orionis. (Betelgueze.)	β Geminorum. (Pollux.)
α Eridani. (Achernar.)	α Leonis. (Regulus.)

These stars—20 in number—will be found to be nearly equally divided between the Northern and Southern hemispheres, that is to say, 9 are Northern and 11 Southern stars.

From the earliest ages of antiquity it has been the custom to arrange the stars in groups or constellations, for the purpose of more readily distinguishing them; each group having appropriated to it some special figure to which the configuration of its stars may be supposed to bear a resemblance, though, in the

majority of instances, this resemblance is imaginary. Modern astronomers have continued this arrangement chiefly on account of the confusion that would arise were it now to be abandoned. We often find that one constellation contains an isolated portion of another, just as one English county sometimes wholly surrounds a parish belonging to another. Stars, too, often occur under different names[d]. Many catalogue-stars have no existence, but owe their creation to mistakes of observers. Constellations are recognised by some and not by others; while the same names are repeated in different parts of the heavens: such are a few of the anomalies of the present system[e].

The constellations will again be referred to in a subsequent chapter.

Concerning the comparative brilliancy of the stars, we know little for certain. Sir W. Herschel gave the following table of the light emitted by stars of different magnitudes, as deduced from his own observations, an average star of the 6th magnitude being taken as unity.

6th magnitude	= 1		3rd magnitude	= 12	
5th ,,	= 2		2nd ,,	= 25	
4th ,,	= 6		1st ,,	= 100	

Sir J. Herschel ascertained that the light of *Sirius* (the brightest of all the fixed stars) is about 324 times that of an average star of the 6th magnitude. From direct photometrical experiments, Dr. Wollaston found that the light of the Sun, as received by us, exceeded by 20,000,000,000 times that of Sirius; consequently, in order that the Sun might appear to us no brighter than Sirius, it must be removed from us not less than 13,433,000,000,000 miles—a distance utterly beyond the limits of human comprehension.

The different degrees of brilliancy observable in the stars may be due to one or other of the following reasons:—Either (1) they are all of the same size, but situated at different distances; or (2) they are of different sizes, but at the same distances. If we suppose the first to be the true hypothesis, and take the light of a star of each magnitude to be half that of the magnitude next

[d] Baily, in the *Brit. Assoc. Cat.* of Stars, p. 75, gives a list of some of these.

[e] See remarks by Baily in the Introduction to the *B. A. C.*, p. 52 *et seq.*

above it, we find that the distance of a star of the 16th magnitude cannot be less than 362 times that of a star of the 1st magnitude[f]; and "as it has been considered probable from recondite investigations, that the average distance of a star of the 1st magnitude from the Earth is 986,000 radii of our annual orbit," it follows that a 16th-magnitude star is distant from us 32,634,292,000,000,000 miles—a distance which light, with a velocity of 186,660 miles per second, would occupy more than 5000 years in traversing! But calculations such as this may be pronounced valueless, for the simple reason that all analogy impels us to suppose that stars, like other celestial objects, are both of diverse size and situated at diverse distances.

The actual distances from the Sun of a few stars have however been ascertained.

The determination of the distance of the stars is effected by ascertaining by instrumental observations the amount of their annual parallax, or displacement in the heavens. The non-detection of stellar parallax afforded for a long time a much resorted to, and certainly to some extent plausible, argument against the soundness of the Copernican theory of the universe. Since it happens that the stars, with few exceptions, do not exhibit parallax, and since also the fact of the orbital motion of the Earth round the Sun rests on the most undoubted evidence, it follows that the general absence of parallax can only be ascribed to the fact that the stars must be placed at such distances from us, that, comparatively speaking, the Earth's orbit, which has a diameter of 183,000,000 miles, is something utterly insignificant,—a mere point, when considered in reference to the distances of the stars themselves.

It might be supposed that since the character and laws of parallax are so clearly understood as they are, the discovery of its existence could present no great difficulty. Nevertheless, nothing in the whole range of astronomical research has more baffled the efforts of observers than this question. This has arisen altogether from the extreme minuteness of its amount. It is quite certain that the parallax does not amount to so much as 1″ in the case of any of the numerous stars which have been as yet submitted to the course of observation which is necessary to

[f] Sir J. Herschel.

discover the parallax. Now, since in the determination of the exact uranographical position of a star there are a multitude of disturbing effects to be taken into account and eliminated, such as refraction, precession, nutation, aberration, and others, besides the proper motion of the star, which will be explained hereafter; and since, besides the errors of observation, the quantities of these influences are all subject to more or less uncertainty, it will astonish no one to be told that they may entail, upon the final result of the calculation, an error of 1″; and, if they do this, it is vain to expect to discover such a residual phenomenon as parallax, the entire amount of which is less than 1″.

An object, whatever be its size, subtends an angle of 1″ when removed to a distance of 206,265 times its own dimensions.

If in any case the parallax could be determined, the distance of the star could be immediately inferred. For, if this value of the parallax be expressed in seconds, or in decimals of a second, and if r denote the semidiameter of the Earth's orbit, d the distance of the star, and p the parallax, we shall have—

$$d = r \times \frac{206265}{p}.$$

If, therefore, $p = 1''$, the distance of the star would be 206,265 times the distance of the Sun; and since it may be considered satisfactorily proved that no star which has ever yet been brought under observation has a parallax greater than this, it may be affirmed that the star in the universe nearest to the solar system is at a distance from it, *at least,* 206,265 times as great as that of the Earth from the Sun.

Let us consider more attentively the import of this conclusion. The distance of the Sun, expressed in round numbers (and this is sufficient for our present purpose), is 91½ millions of miles. If this be multiplied by 206,265, we shall obtain,—not indeed the distance of the nearest of the fixed stars,—but the *inferior limit* of that distance, that is to say, a distance within which the star cannot lie. This limit, expressed in miles, is

$$d = 206{,}265 \times 91{,}430{,}000 = 18{,}858{,}800{,}000{,}000 \text{ miles},$$

or nearly 19 *billions of miles.*

In the contemplation of such numbers the imagination is lost, and no clear conception remains, except that of the mere

arithmetical expression of the result of the computation. Astronomers themselves, accustomed as they are to deal with stupendous numbers, are compelled to seek for units of proportionate magnitude to bring the arithmetical expression of the quantities within moderate limits. The motion of light supplies one of the most convenient moduli for this purpose, and has, by common consent, been adopted as the unit in all computations the object of which is to gauge the universe. It is known that light moves at the rate of 186,660 miles per second. If, then, the distance d above computed be divided by 186,660, the quotient will be the time, expressed in seconds, which light takes to move over that distance. But since even this will be an unwieldy number, it may be reduced to minutes, hours, days, or even to years.

In this manner we find that, if any star have a parallax of 1″, it must be at such a distance from our system that light would take 3·202 years, or 3 years and 74 days, to come from it to the Earth.

If then the space through which light moves in a year be taken as the unit of stellar distance, and p be the parallax expressed in seconds, or decimals of a second, we shall have

$$d = \frac{3 \cdot 202}{p}.$$

It will easily be imagined that astronomers have diligently directed their efforts to the discovery of some change of apparent position, however small, produced upon the stars by the Earth's motion. As the stars most likely to be affected by the motion of the Earth are those which are nearest to the system, and therefore probably those which are brightest and largest, it has been to such that this kind of observation has been chiefly directed; and since it was certain that, if any observable effect be produced by the Earth's motion at all, it must be extremely small, it is only from the nicest and most delicate means of observation that any discovery of this nature could be expected.

One of the earlier expedients adopted for the solution of this problem was the erection of a telescope, of great length and power, in a position permanently fixed—attached, for example, to the side of a pier of solid masonry, erected upon a foundation of rock. This instrument was screwed into such a position that particular

stars, as they crossed the meridian, would necessarily pass within its field of view. Micrometric wires were, in the usual manner, placed in its eye-piece, so that the exact point at which the stars passed the meridian each night could be observed and recorded with the greatest precision. The instrument being thus fixed and immoveable, the transits of the stars were noted each night, and a record was made of the exact places where they passed the meridian. This kind of observation was carried on through the year; and if the Earth's change of position, by reason of its annual motion, should produce any effect upon the apparent position of the stars, it was anticipated that such effect would be discovered by these means. After, however, making all allowance for the usual causes which affect the apparent position of the stars, no change of position was discovered which could be assigned to the Earth's motion [g]. A tube of this kind was used at Greenwich by Pond.

Only a few stars are certainly *known* to possess a sensible parallax. Particulars of them are given in the table on p. 480, which has been calculated on the assumption that the Sun's parallax = 8·87, and that the velocity of light = 186,660 miles per second.

Stars are distinguished from one another in various ways. The ancients were in the habit of indicating the locality of a star by its position in the constellation to which it belonged; thus Aldebaran was called *Oculus Tauri.* This custom was also followed by the Arabians, and, indeed, many of the names applied by them are still retained in a corrupted form; thus Betelgueze (α Orionis) is a corruption of *ibt-al-jauza*, signifying "the shoulder of the Jauza (or 'Central one')." Bayer, the German astronomer, was the first to improve upon the old plan, which he did by publishing in 1603 a celestial atlas, in which the stars of each constellation were distinguished by the letters of the Greek alphabet; the brightest receiving the distinctive mark of α, the next β, and so on. Bayer's letters are still in common use, the name of the constellation in the genitive case being put after each; thus Procyon is termed α Canis Minoris; Vega, α Lyræ; Arcturus, α Boötis. It should be remarked that, owing either to carelessness on the part of

[g] The preceding remarks on stellar parallax are taken (with slight alterations) from the *Museum of Science.*

Bayer, or to changes in the brightness of the particular stars, or to both causes combined, this alphabetical arrangement in many cases does not accurately represent the relative brilliancy of the different stars in a constellation Flamsteed affixed *numbers* to the stars observed by him, which numbers referring to the order of R. A. in each constellation are still in use.

Star.	Parallax.	Distance.		Observer.
		Sun's distance = 1.	Time of its light reaching the Earth.	
	"		Years.	
α Centauri	0·918	224,700	3·51	Maclear.
61 Cygni	0·563	366,400	5·73	Auwers.
21185 Lalande	0·511	403,600	6·31	Winnecke.
β Centauri	0·470	438,900	6·87	Maclear.
μ Cassiopeiæ	0·342	603,100	9·43	O. Struve.
34 Groombridge ..	0·307	671,900	10·51	C. A. Peters.
21258 Lalande	0·271	761,100	11·91	Auwers.
17415 Oeltzen	0·247	835,100	13·06	Krüger.
Sirius	0·193	1,068,700	16·72	Von Gylden.
α Lyræ	0·180	1,145,900	17·93	Brunnow (mean).
70 Ophiuchi	0·169	1,220,500	19·09	Krüger.
ι Ursæ Majoris ..	0·133	1,550,900	24·26	C. A. F. Peters.
Arcturus	0·127	1,624,000	25·41	C. A. F. Peters.
γ Draconis	0·092	2,242,000	35·07	
1830 Groom. Urs. Maj.	0·090	2,291,000	35·85	Brünnow.
Polaris	0·076	2,714,000	42·45	C. A. F. Peters.
3077 Bradley	0·070	2,946,000	46·09	Brünnow.
85 Pegasi	0·050	4,125,000	64·53	Brünnow.
α Aurigæ	0·046	4,484,000	70·14	C. A. F. Peters.
σ Draconis	0.025	8,254,000	129·06	Brünnow.

The subject of the photometry of stars, though one of much importance, has received but little attention from practical astronomers. The common method of classifying stars into arbitrary magnitudes is both vague in theory and contradictory in practice. It is vague, inasmuch as the place of a star in the scale of magnitudes conveys but little definite idea of the actual brilliancy thereof;

and it is contradictory in a remarkable degree, inasmuch as the same star has in numberless instances a different magnitude assigned to it by different authorities[h].

The first observer who attempted stellar photometry on any organised basis was Sir J. Herschel, who formed a Table of Stars arranged in order of brightness. This Table is too well known to need further reference here[i]. In Germany the subject has received a good deal of attention, and the names of Heis, Seidel, and Zöllner may be mentioned in connection with it.

Seidel has published an elaborate catalogue of 206 conspicuous stars arranged progressively in the order of brightness as determined (I believe) by an "astro-photometer" invented by Steinheil. The following are the first 20 stars in Seidel's list, with the relative values assigned by him to each[k]:—

α Canis Majoris	4·286	α Leonis	0·325
α Lyræ	1·000	α Cygni	0·310
β Orionis	0·993	ε Canis Majoris	0·309
α Aurigæ	0·818	α Tauri	0·303
α Boötis	0·794	α Scorpii	0·291
α Canis Minoris	0·700	β Geminorum	0·289
α Aquilæ	0·489	α Geminorum	0·256
α Virginis	0·485	γ Orionis	0·255
α Orionis	0·359	β Tauri	0·229
α Piscis Australis	0·339	ζ Orionis	0·220

The practice of giving names to the stars is of early date, and probably originated with the Chaldæans. Intimations of this custom may be found in the Holy Scriptures:—

"Which maketh *Ash*, *Kesil*, and *Kimah*, and the chambers of the south[l]."

"Canst thou bind the sweet influences of *Kimah*, or loose the bands of *Kesil*? Canst thou bring forth *Mazzaroth* in his season? Or canst thou guide *Ash* with his sons[m]?"

"Seek him that maketh *Kimah* and *Kesil*[n]."

[h] Sir J. Herschel, *Results of Ast. Obs.*, p. 304. See remarks by Pogson in *Radcliffe Obs.*, vol. xv. p. 295. 1854.

[i] *Outlines of Ast.*, p. 705.

[k] Seidel's Table, together with that of Zöllner, will be found in Klein's *Handbuch: Der Fixsternhimmel*, p. 26. See a Paper by L. Seidel in *Abhandlungen der K. Bayr. Akademie der Wissenschaften*, 6th class, vol. iii. 1852.

[l] *Job*, ix. 9.

[m] *Job*, xxxviii. 31–2.

[n] *Amos*, v. 8. It is not known for certain what stars or constellations are referred to in these verses, but the rendering given in our translation rests on insufficient authority. It is probable, however, that Mazzaroth may mean the circle of the zodiac, but the others are doubtful. Parkhurst (*Lexicon*) thinks that the application of the Greek names of certain constellations to the Hebrew originals, as is done in the Authorised Version, here and elsewhere, and by the

The invention of the Zodiac has been ascribed to the Egyptians. Dupuis especially advocated this opinion, and thought that the constellations in question had reference to the division of the seasons, and to the agriculture in vogue at the time of their invention. He supposed Cancer to represent the retrogradation of the Sun at the solstice, and Libra the equality of the day and night at the equinoxes. This idea is undoubtedly supported by several curious coincidences: for instance, the inundation of the Nile, which takes place after the summer solstice, happens when the Sun is in Aquarius and Pisces; and Virgo, usually represented as a woman holding an ear of corn, coincides with the time of the Egyptian harvest.

The insuperable objection to this theory is the excessive antiquity which it assigns to the zodiac (not less than 15,000 years). As this is historically inadmissible, and directly opposed to Divine Revelation, Dupuis gets over the difficulty by supposing the names to have been given, not to the constellations in conjunction, but to those in opposition to the Sun. This only requires the constellations to have been devised B.C. 2500 ± ; in this form the idea is adopted by Laplace and others as correct [o]. It has been asserted that the Jews were acquainted with the zodiac, and that in *Gen.* i. 14 the uses of the heavenly bodies—to divide the seasons, years, and days—are set forth.

Seneca attributes the sub-division of the heavens into constellations to the Greeks, 1400 or 1500 years B.C. [p] It may be mentioned as a somewhat singular fact, that the Iroquois, a North American Indian tribe, should have applied the name of "The Bear" to the group Ursa Major, in common with the earliest Asiatic nations, so remote from them, more especially as it cannot be said to offer much resemblance to that animal.

The present system of constellations, though on the whole useful, presents many anomalies, which require reform. Thus Aries should no longer have a horn in Pisces and a leg in Cetus; nor should 13 Argûs pass through the flank of Monoceros into

LXX previously, is only fanciful. Barnes, however (*Notes on Job*), derives *Kimah* from a root signifying a heap, and applicable to the Pleiades, and *Kesil* from another root signifying *to be strong*, and thus applicable to that constellation known as *the strong man*, corresponding, as may be conjectured, to what the Greeks called *Orion*. (See *Class. Dict.*)

[o] *Hist. of Ast.* L.U.K., p. 16.

[p] *Quæst. Nat.*, lib. vii. cap. 25.

Canis Minor: 51 Camelopardi might with propriety be extracted from the eye of Auriga; and the ribs of Aquarius released from 46 Capricorni. But these are all matters as to which it is probably hopeless to expect extensive improvements in the present day.

With reference to the present mode of identifying stars by letters, it may be remarked that though the idea was carried out practically by Bayer[q], as mentioned above, yet Piccolomini, who was born at Siena in 1508 and died there in 1578, did the same thing. The letter system is defective in this respect, that in large constellations the alphabet is very soon used up: indeed, as Mr. Baily remarks, La Caille has, in the constellation Argo alone, besides the Greek alphabet, employed the whole of the Roman alphabet, both in small and capital letters, each of them more than 3 times; in fact he has used nearly 180 letters in that constellation alone. "Thus we have 3 stars marked *a*, and 7 marked A; 6 marked *d*, and 5 marked D; and so on with several others."

As increased attention came to be paid to the study of the heavens, the number of enumerated stars was, as might be expected, augmented. The following table[r] exemplifies this. It

	Ptolemy.	Tycho Brahe.	Hevelius.	Flamsteed.	Bode.
Aries	18	21	27	66	148
Ursa Major	35	56	73	87	338
Boötes	23	28	52	54	319
Leo	35	40	50	95	337
Virgo	32	39	50	110	411
Taurus	44	43	51	141	394
Orion	38	62	62	78	304

shews the number of stars reckoned in certain constellations by 5 different catalogue-makers living at different epochs.

The ideas of the ancients on the fixed stars were very obscure.

[q] Bayer was likewise an astrologer. In the 1st edition of the *Uranometria* he marked many objects supposed to have some kind of influence over mundane affairs.

[r] A fuller one will be found in the *Encycl. Met.*, art. "Astronomy," p. 506.

Anaximenes (550 B.C.) thought that the stars were designed for ornament, and nailed, as it were, like studs in the crystalline sphere. Pythagoras pronounced each star to be a distinct world with its own land, water, and air. The Stoics, Epicureans, and indeed almost all the ancient schools of philosophy, held that the stars were celestial fires nourished by the caloric or igneous matter which they believed ever to stream out from the centre of the universe. Anaxagoras (450 B.C.) considered that the stars were stones whirled upwards from the Earth by the rapid motions of the ambient ether, the inflammable properties of which setting them on fire caused them to appear as stars. Callimachus describes the circumpolar stars as feeding on air; and Lucretius, pondering on the subject, and not doubting the fact, asks "Unde æther sidera pascit?" (How does the æther nourish the stars?) Stars were at one time looked upon as the *spiraculæ*, or breathing-holes of the universe.

Sir John Herschel's remarks on the stars are very forcible. He says: "The stars are the land-marks of the universe; and amidst the endless and complicated fluctuations of our system, seem placed by its Creator as guides and records, not merely to elevate our minds by the contemplation of what is vast, but to teach us to direct our actions by reference to what is immutable in His works. It is indeed hardly possible to over-appreciate their value in this point of view. Every well-determined star, from the moment its place is registered, becomes to the astronomer, the geographer, the navigator, the surveyor, a point of departure which can never deceive or fail him, the same for ever and in all places, of a delicacy so extreme as to be a test for every instrument yet invented by man, yet equally adapted for the most ordinary purposes; as available for regulating a town clock as for conducting a navy to the Indies; as effective for mapping down the intricacies of a petty barony as for adjusting the boundaries of transatlantic empires. When once its place has been thoroughly ascertained and carefully recorded, the brazen circle, on which that useful work was done, may moulder, the marble pillar totter on its base, and the astronomer himself survive only in the gratitude of his posterity: but the record remains, and transfuses all its own exactness into every determination which takes it for a ground-work, giving to inferior instruments, nay, even to temporary contrivances, and to the

observations of a few weeks or days, all the precision attained originally at the cost of so much time, labour, and expense [s]."

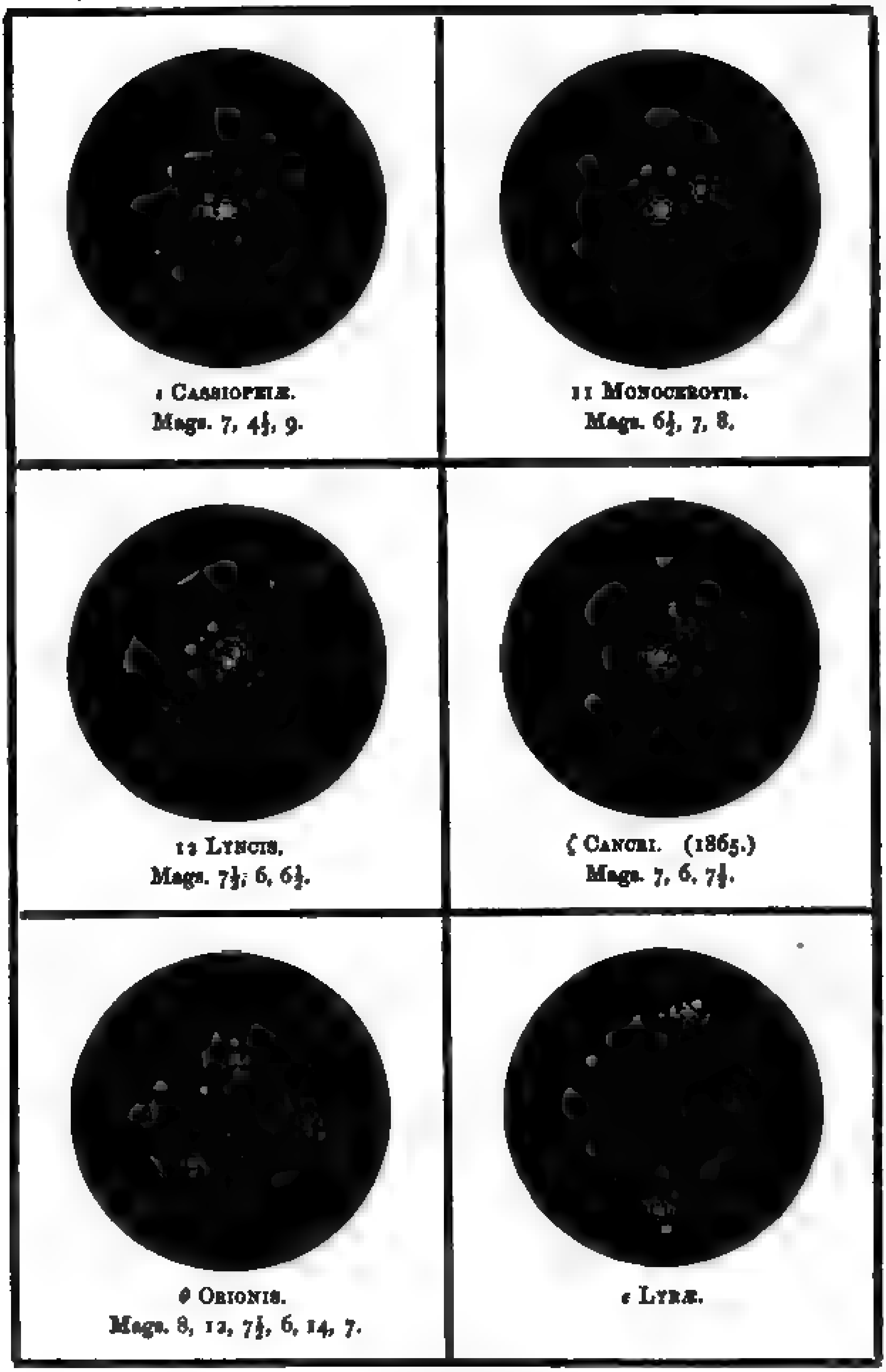
Some investigations have been made by Stone having for their object the determination of the question whether the stars transmit to us any measureable amount of heat. The investigations alluded to were carried out at the Greenwich Observatory in 1869 by the aid of a thermo-electric pile connected with the great 12¾-inch refractor of that Observatory, and yielded some sensibly affirmative results [t]. Some experiments by Huggins led him to the same conclusion [u].

[s] *Mem.* R.A.S., vol. iii. p. 125. 1829.

[t] *Proc. Roy. Soc.*, vol. xviii. p. 159, Jan. 1870; *Phil. Mag.*, 4th ser. vol. xxxix. p. 376. May 1870.

[u] *Ast. Reg.*, vol. vii. p. 85. April 1869.

Figs. 134–139. *Plate* XXI.



MULTIPLE STARS.

(*Drawn to scale by G. F. Chambers.*) Scale = 30″ to the inch (except ε Lyræ).

The Magnitudes are noted from left to right.

CHAPTER II.

DOUBLE STARS, ETC.

But few known until Sir W. Herschel commenced his search for them.—Labours of Sir J. Herschel and F. G. W. Struve.—Examples.—Optical Double Stars.—Binary Stars.—Discovered by Sir W. Herschel.—Examples.—List of Optical Doubles.—Coloured Stars.—Examples.—Generalisations from Struve's Catalogue.—Stars changing colour.—Triple Stars.—Quadruple Stars.—Multiple Stars.

ALTHOUGH to the unaided eye all the stars appear single, yet in numerous instances the application of suitable optical assistance shews that many consist in reality of 2 stars, placed in juxtaposition so close together that they appear to the unassisted eye as one. These are termed *double* stars[a]. Only 4 of these objects were known until Sir W. Herschel, by means of his powerful telescopes, discovered a large number the existence of which had never before been suspected. He observed and catalogued altogether about 500, which subsequent observers, especially F. G. W. Struve and Sir J. Herschel, have augmented to nearly 10,000.

The following (p. 488) have been selected by Sir J. Herschel[b] from Struve's Catalogue as remarkable examples of each class, well adapted for observation by amateurs who may be disposed to try by them the efficiency of telescopes.

If two stars lie very nearly in the same line of vision, whatever their distance from each other, they will form an *optical* double star, or one the components of which are only apparently and not really in juxtaposition. Sir W. Herschel, thinking that a

[a] The first application of this term was by Ptolemy, who called ν Sagittarii, διπλοῦς.

[b] *Outlines of Ast.*, p. 609, kindly revised by Dawes for this work. But that able observer once told me that he attached no great importance to such lists so far as regards the *testing* of telescopes.

0" to 1".	Mags.	1" to 2".	Mags.	2" to 4".	Mags.	4" to 8".	Mags.
γ^2 Andr.	5½	π Aquilæ	6 —7	ζ Aquarii	4 —4½	υ Argûs	3 —8
36 Andr.	6 —7	ζ Boötis	3½—4½	ε Boötis	3 —7	ω Aurigæ	5 —9
ε Arietis	5 —6½	2 Camelop.	5½—7½	μ Can. Maj.	5½—9½	ξ Boötis	3½—6½
52 Arietis	6½—7	ι^2 Cancri	8	σ Cassiop.	6 —8	π Boötis	3½—6
4 Aquarii	6 —8	ι Cassiop.	5 —7	γ Ceti	3 —7	44 Boötis	5 —6
5 Aquarii	6	π Cephei		γ Cor. Aust.	6 —6	ρ Capricorni	5 —9
χ Aquilæ	6	ε Chamæl.	6 —6½	σ Cor. Bor.	6 —6½	η Cassiop.	4 —7½
ζ Cancri	6 —7	γ Circini	5½—6	ε Draconis	5½—9	κ Cephei	4½—8½
λ Cassiop.	5	η Cor. Bor.	6 —6½	μ Draconis	4 —4½	ξ Cephei	5 —7
γ Centauri	4 —4	δ Cygni	3½—9	ρ Herculis	4 —5½	ζ Cor. Bor.	5 —6
42 Co. Ber.	4½—5	λ Ophiuchi	4 —6	β Hydræ	5 —5	α Crucis	2 —2
γ Cor. Bor.	5	τ Ophiuchi	5 —6	ε Hydræ	4 —8½	μ Cygni	5 —6
λ Cygni	5 —6	52 Orionis	6 —6½	γ Leonis	2 —4	μ Eridani	5
φ Draconis	5			ι Leonis	4 —7½	12 Eridani	4 —7
ζ Herculis	3 —6			κ Leporis	5 —9	32 Eridani	5 —7
ω Leonis	6½—7½			ζ Orionis	3 —6½	α Geminor.	3 —3½
γ Lupi	4 —4			α Piscium	5 —6	δ Geminor.	3½—9
π Lupi	5½—6½			δ Serpentis	3 —5	α Herculis	3½—5½
32 Orionis	5 —7			ε Trianguli		95 Herculis	5½—6
66 Piscium	6 —7			ι Trianguli	5½—7	70 Ophiuchi	4½—7
27 Pleiad.	5			ξ Urs. Maj.	4 —5½	λ Orionis	4 —6
ξ Scorpii						ζ Phœnicis	5½—10
φ Urs. Maj.	5					γ Virginis	4 —4

8" to 12".	Mags.	12" to 16".	Mags.	16" to 24".	Mags.	24" to 32".	Mags.
γ Arietis	4½—5	κ Boötis	5½—8	α Can. Ven.	2½—6½	χ Cygni	5 —9
ζ Antliæ	6 —7	α Centauri	1 —2	24 Co. Ber.	5½—7	ψ Draconis	5½—6
2 Can. Ven.	6 —9	β Cephei	3 —8	κ Cor. Aust.	7 —7½	κ Herculis	5½—7
γ Delphini	4 —7	η Lupi	4 —8½	61 Cygni	5½—6	η Lyræ	5 —9
θ Eridani	4½—5½	8 Monocer.	5½—8	41 Draconis	5½—6	23 Orionis	5 —7
f Eridani	5 —5½	β Scorpii	2 —5½	δ Herculis	4 —8½		
β Orionis	1 —9	ζ Urs. Maj.	3 —5	ε Normæ	5½—7½		
		γ Volantis	5 —7	61 Ophiuchi	7½—7½		
				ζ Piscium	6 —8		
				θ Serpentis	4½—5		
				χ Tauri	6 —8		
				α Urs. Min.			

prolonged and careful scrutiny of some of these double stars (mere optical doubles as he regarded them) might ultimately afford data for determining their parallax, applied himself in 1779 and subsequent years to the formation of an extensive catalogue, embodying measurements of position and distance for future reference. "On resuming the subject, his attention was diverted from the original object of the inquiry by phenomena of a very unexpected character, which at once engrossed his whole attention. Instead of finding, as he expected, that annual fluctuation to and fro of one component of a double star with respect to the other—that alternate increase and decrease of their distance and angle of position which the parallax of the Earth's annual motion would produce—he observed in many instances a regular progressive change; in some cases bearing chiefly on their distance, in others on their position, and advancing steadily in one direction, so as clearly to indicate a real motion of the stars themselves, or a general rectilinear motion of the Sun and whole solar system, producing a parallax of a higher order than would arise from the Earth's orbital motion, and which might be called systematic parallax." To put the matter in a few words, in 1802 Herschel announced to the Royal Society, in a memorable paper, the existence of sidereal systems, consisting of 2 stars revolving about each other in regular elliptic orbits, and constituting *binary* stars—a term introduced to distinguish them from optical double stars, in which no periodic change of place is discoverable [c].

The double stars which after the lapse of 25 years were found by Herschel to possess an orbital motion were about 50 in number; subsequent observers have added many more, and fully 600 stars are now recognised to be in motion.

The following table furnishes information concerning some of the more remarkable of these objects, together with the elements of their orbits determined by the several computers named, on the principles of the Newtonian law of gravitation—a law which was first practically applied to this branch of sidereal astronomy

[c] *Phil. Trans.*, vol. xciii. p. 339, 1803; see also vol. xciv. p. 353, 1804. It may be worth mentioning that Lambert (*Lettres Cosmologiques*) and Mitchell (*Phil. Trans.*, vol. lvii. p. 234, 1767) both conjectured the existence of binary stars. Lambert's book was *re-written* by M. Mérian and published in French at Berlin in 1784 under the title of *Système du Monde par M. Lambert*: a translation of this corrupted edition was made into English by J. Jacque, and published at London in 1800 under the title of *The System of the World*.

by M. Savary in 1830, in the case of ξ Ursæ Majoris[d]. In the case of 2 of the stars mentioned in the table, namely σ Coronæ and α Geminorum, periods differing widely have been deduced by different computers. Klinkerfues assigns for σ Coronæ a

Star.	Period.	PP.	Semi-axis Major.	e	Calculator.	Reference.
	Years.		$''$			
42 Comæ Berenices	25·7	1869·9	0·65	0·48	Dubiago	M. N. xxxv. 370.
ζ Herculis	34·2	1830·0	1·22	0·42	Duner	A. N. 1868.
3121 Σ Cancri ..	40·6		0·69	0·37	Fritsche	*Bull. Acad. S. Pet.* x. 92.
η Coronæ Borealis ..	41·5	1850·2	0·82	0·26	Duner	A. N. 1868.
ξ Libræ	49·0	1860·6	1·74	0·97	Thiele	A. N. 1199.
γ Coronæ Australis	55·5	1882·7	2·40	0·69	Schiaparelli	A. N. 2073.
ξ Ursæ Majoris ..	60·6	1875·6	2·58	0·38	Hind	M. N. xxxiii. 101.
ζ Cancri	62·4	1869·3	0·90	0·00	O. Struve	M. N. xxxv. 228.
α Centauri	76·2	1862·7	20·13	0·63	E. B. Powell	M. N. xxx. 192.
70 Ophiuchi	94·3	1808·8	4·90	0·49	Schur	A. N. 1682.
λ Ophiuchi	95·9	1791·2	0·84	0·47	Hind	Klein, ii. 207.
ω Leonis	107·6	1842·7		0·50	Doberck	A. N. 2078.
3062 Σ Cassiopeiæ ..	112·6	1835·2	1·31	0·50	Schur	
ξ Boötis	168·9	1779·7	9·95	0·78	Hind	M. N. xxxii. 250.
η Cassiopeiæ	181·0	1715·0	10·33	0·77	E. B. Powell	M. N. xxi. 66.
γ Virginis	182·1	1836·4	3·58	0·87	J. Herschel	
τ Ophiuchi	185·2	1820·6	1·11	0·58	Doberck	A. N. 2037.
ω Leonis	227·7	1841·4	1·30	0·72	Klinkerfues	
1938 Σ Boötis ..	314·3	1860·8	1·76	0·56	Hind	M. N. xxxii. 250.
γ Leonis	402·6	1741·1	2·08	0·73	Doberck	M. N. xxxv. 397.
δ Cygni	415·1	1904·1	2·31	0·28	Behrmann	
61 Cygni	452·0		15·4			
σ Coronæ Borealis .	843·2	1828·9	6·00	0·75	Doberck	A. N. 2037.
α Geminorum ..	996·8	1750·3	7·53	0·34	Thiele	A. N. 1227.

period of only 420 years; whilst for α Geminorum we have 232^y (Madler); 252^y (Sir J. Herschel); 632^y (Hind); and 996^y

[d] *Conn. des Temps*, 1830, p. 56. Four observations in position and distance are necessary for laying down the orbit of a binary star. Encke's method will be found in the *Berliner Astronomisches Jahrbuch*, 1832, p. 253, and Sir J. Herschel's in *Mem.* R.A.S., vol v. p. 171, 1833. See also Arago's *Pop. Ast.*, Eng. ed., vol. i. p. 301.

(Thiele) as in the table. Such substantial discrepancies are not often met with in Astronomy.

The work of cataloguing double stars, initiated by Sir W. Herschel, was followed up with great assiduity by W. Struve, whose large catalogue of 3112 stars—the *Mensuræ Micrometricæ*—was published at St. Petersburg in 1837. Other subsidiary catalogues were also published at different times by this observer. The system which he adopted was to divide all the double stars measured by him into 8 classes, and each class into 2 sub-classes, according to the angular distance of the components. The 8 principal classes were as follows:—

	Dist.		Dist.
	$''$		$''$
I.	less than 1	V.	between 8—12
II.	between 1—2	VI.	12—16
III.	2—4	VII.	16—24
IV.	4—8	VIII.	24—32

The arrangement of the sub-classes had regard to the magnitudes of the component stars. The 1st sub-class of every principal class consisted of conspicuous doubles, or, as Struve called them, *duplices lucidæ;* the 2nd of less important doubles, or *duplices reliquæ*. The former comprised stars each component of which exceeded in brightness the 8½ magnitude; the latter, stars between the magnitudes 8½ and 12—which last was assumed to be the smallest visible in the telescope employed (the Dorpat refractor of 15 English inches aperture). Struve's system is arbitrary and inconvenient, for these reasons—that double stars which are also binaries (as many are) frequently pass from one class to another in the course of a few years, and likewise that the magnitudes are not comparable with those assessed on the common scale. Neither Struve's classification nor his scale of magnitudes have been generally adopted by subsequent observers. References to W. Struve's catalogue are generally indicated thus—Σ. Stars observed and catalogued by his son Otto Struve are frequently indicated thus—σ.

Of late years the subject of double stars has received much attention from Smyth, Dawes, Jacob, Main, Fletcher, and Webb in England; from Secchi and Dembowski on the Continent; and from Burnham in America. A comprehensive general catalogue

of all the known double stars (embodying the numerous observations of recent years) is now a desideratum.

According to Smyth, of 653 stars in Struve's 8 orders there are probably only 48 which are optically double. Of the wider ones none have so changed in position as to enable any orbit to be determined, whence it is concluded that even where they have a physical connexion the period of revolution cannot be less than 20,000 years. This statement was made more than 30 years ago, and should perhaps now be qualified.

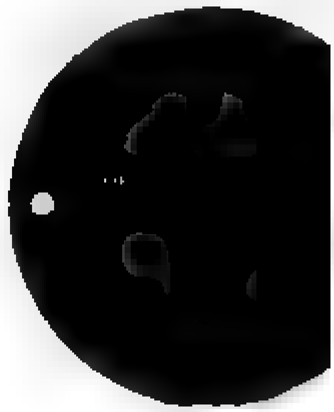
The following are given by Smyth as a few of the more remarkable optically-double stars:—

	Mags.	Dist.
		″
Vega (α Lyræ)	1 —11 ..	43
Aldebaran (α Tauri)	1 —12 ..	108
Altair (α Aquilæ)	1½—10 ..	152
Pollux (β Geminorum) ..	2 —12 ..	208

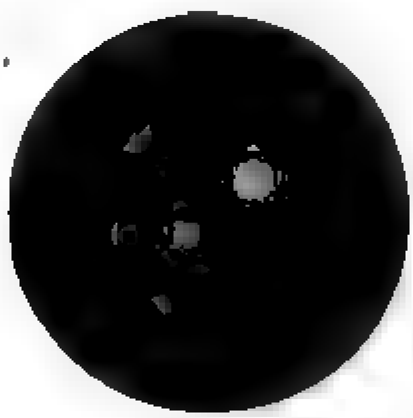
Many double stars exhibit the curious and beautiful phenomenon of complementary colours. In such instances the larger star is usually of a ruddy or orange hue, and the smaller one blue or green. When complementary colours are found in a double star the components of which are of very unequal size, we may attribute the circumstance mainly to the effect of contrast; yet it can hardly be doubted that in many cases colour truly exists. Single stars of a fiery red or deep orange are not uncommon, but isolated blue or green stars are very rare. Amongst the conspicuous stars β Libræ (green) appears to be the only instance. The following may be cited as good examples of coloured pairs:—

Name.	R.A. 1870.	Decl. 1870.	Mag. of Components.	Colour of A.	Colour of B.
	h. m. s.	° ′			
η Cassiopeiæ ..	0 41 15	+57 7·8	4 7½	Yellow	Purple.
α Piscium	1 55 18	+ 2 8·1	5 6	Pale green ..	Blue.
γ Andromedæ	1 55 55	+41 42·4	3½ 5½	Orange	Sea green.
ι Cancri......	8 38 49	+29 14·0	5½ 8	Orange	Blue.
ε Boötis......	14 39 18	+27 37·4	3 7	Pale orange	Sea green.
ζ Coronæ ...	15 34 29	+37 3·6	5 6	White	Light purple.
α Herculis....	17 8 43	+14 32·2	3½ 5½	Orange	Emerald green.
β Cygni	19 25 28	+27 41·3	3 7	Yellow	Sapphire blue.
σ Cassiopeiæ..	23 52 26	+55 1·8	6 8	Greenish ..	Bright blue.

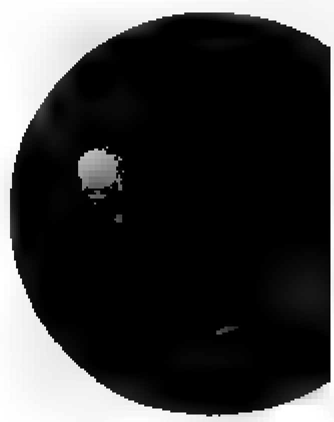
γ Andromedae.



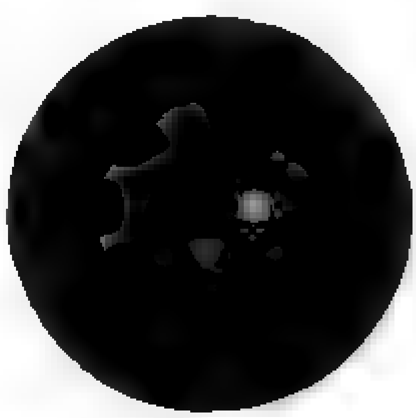
B Leporis.



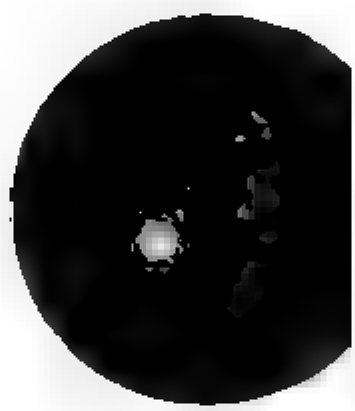
ι Boötis.



β Cygni.



σ Cassiopeiae.



η Cassiopeiae.

COLOURED STARS.

The following are some generalisations from Struve's catalogue[e]. Of 596 bright double stars there were:—

375 pairs of the same colour and intensity.
101 pairs of the same colour but different intensity.
120 pairs of totally different colours.

Amongst those of the same colour the white greatly predominated, and of 476 specimens of that species there were:—

295 pairs both white.
118 pairs yellowish or reddish.
63 pairs both bluish.

Webb thus comments on this analysis:—"The curious fact is here made evident that when the brighter star is not white, it approaches the less refrangible end of the spectrum, and the reverse: so that the very remarkable statement of J. Herschel that 'no green or blue star (of any decided hue) has, we believe, ever been noticed unassociated with a companion brighter than itself,' is shown to be, if not literally, yet substantially correct[f]."

The number of the reddish stars is double that of the bluish stars; and that of the white stars is $2\frac{1}{2}$ times as great as the number of red ones. The combination of a blue companion with a coloured primary happens:—

53 times with a white principal star.
52 times with a light yellow.
52 times with a yellow or red.
16 times with a green.

Of isolated stars which are both large in size and noticeable in colour the following may be mentioned:—

White stars.—α Canis Majoris, α Leonis, β Leonis, α Piscis Australis, α Ursæ Minoris.
Red stars.—α Tauri, α Scorpii, α Orionis.
Blue stars.—α Aurigæ, β Orionis, γ Orionis, α Canis Minoris, α Virginis.
Green stars.—α Lyræ, α Aquilæ, α Cygni.
Yellow stars.—α Boötis.

The question of change in the colour of stars must be answered in the affirmative, though the examples yet known are few. Ptolemy and Seneca expressly declare that in their time Sirius was of a

[e] Quoted in Smyth's *Cycle of Cel. Obj.*, vol. i. p. 301. See the original.
[f] *Student*, vol. v. p. 488. Jan. 1871.

reddish hue, whereas now, as is well known, it is of a brilliant white. Capella which was formerly red is now blue. It would also seem that γ Leonis and γ Delphini have changed since they were first observed by Sir W. Herschel. He says[g] that they were perfectly white, whereas now the larger components of each are both yellow, and the smaller both green.

Admiral Smyth once published[h] a diagram of coloured discs to guide observers in assigning colours to stars. The diagram contained 4 shades of each of the following colours, viz.:—red, orange, yellow, green, blue, and purple—but it was of no practical use as an adjunct to the telescope. As Webb has well *insinuated*, to think that one can compare a glittering and flashing point with a wafer-like circle of dead and opaque colour is a futile notion.

When very powerful telescopes are directed upon some stars which with smaller ones are only seen as single stars or doubles, they will be found to consist of 3 or more stars grouped together: such are termed triples, quadruples, quintuples, or multiples, as the case may be. The following are examples, but some of the triples (*e.g.* γ Argûs) might with propriety be ranked as quadruples:—

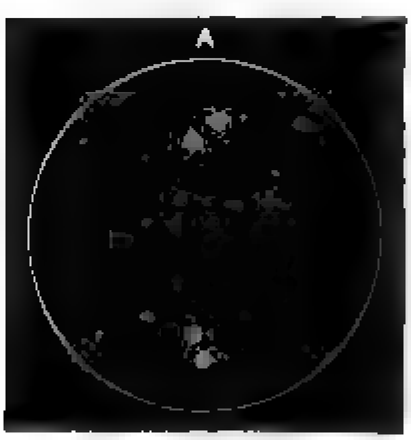
Name.	R. A. 1870.	Decl. 1870.	Magnitudes.	Distance.
Triples.	h. m. s.	° ′		″ ″
ψ Cassiopeiæ	1 16 47	+67 26·9	4½ 9 11	32 2
γ Andromedæ	1 55 55	+41 42·4	3½ 5½ 6	10·3 0·5
3760 H Columbæ ..	5 21 6	−35 27·8	7 7½ 11	7·3 20
11 Monocerotis	6 22 31	− 6 57·0	6½ 7 8	7·2 9·6
12 Lyncis	6 34 44	+59 34·2	6 6½ 7½	1·7 8·7
3928 H. Puppis	7 0 48	−34 35·3	6½ 8½ 10	5·5 37
ζ Cancri	8 4 45	+18 2·4	6 7 7½	0·5 5·4
γ Argûs	8 5 31	−46 56·3	2 6 8	41 62
2837 B.A.C. Volantis	8 20 23	−71 5·3	6 6½ 7	65
A Velorum	8 24 58	−47 29·7	6 9 11	4·4 20
1604 Σ Crateris	12 2 27	−11 6·7	7 9 8	
y Centauri	14 13 20	−57 51·8	5½ 8 11	9·6 35
51 Libræ	15 57 13	−11 0·8	4½ 5 7½	1·1 7·1
3791 South, Sagittarii	17 54 31	−23 2·0	7 11 8	5 15

[g] Quoted in Smyth's *Cycle*, vol. i. p. 303. I have been unable to find the original.
[h] In his *Sidereal Chromatics*. 8vo. Lond. 1864, p. 54.

Name.	R.A. 1870.	Decl. 1870.	Magnitudes.	Distance.
QUADRUPLES.	h. m. s.	° ′		″ ″ ″
π^2 Canis Majoris ..	6 49 23	−20 14·5	6 9½ 10 11	45 52 125
β Lyræ	18 45 15	+33 12·7	3–5 8 8½ 9	46 60 71
5112 H Sagittarii ..	19 15 55	−18 22·7	8 8 8 12	18 20 25
178 P XX. Delphini	20 25 0	+10 49·5	7½ 8 16 9	14 20 0·7
8² Lacertæ	22 30 6	+38 57·7	6½ 6½ 11 10	22 ... 82
MULTIPLES.				
σ Orionis	5 32 13	− 2 40·5	{4, 11, 8, 7, 8½, (D) 9, 8}	{12″, 12, 42, 211; D—9, 8½″, D—8, 68″}
3780 H Leporis . ..	5 33 44	−17 58·6	7, 7, 8, 8, 8	
α Crucis	12 19 23	−62 22·7	{2, 2, 5, 12, 14, 13}	{5, 90, 60, 100, 100, 125}
ε Lyræ	18 40 0	+39 32·0	{5, 6½, 5, 5½, 9½, 13, 13}	
β Capricorni	20 13 42	−15 11·4	3½, 7	205

Several of the above are known to be Binary &c. systems, and perhaps as time goes on and observers multiply we shall find that others will have to be ranked in the same category. For instance, respecting ε Lyræ, Prince notes not only a "considerable increase

Fig. 146.



ε Lyræ. (*Smyth*, 1842.)

Fig. 147.

ε Lyræ. (*Prince*, 1873.)

of brilliancy" in the largest of the trio of small stars which lie between the two principal pairs, but also points out that if Smyth's drawing and description are to be relied on, a change of position has certainly taken place between 1842 and 1873. "The central

acolyte is more nearly midway between the 2 pairs than formerly, while the largest forms with them, very nearly, the apex of a triangle[1]." Assuming that there are grounds for the suspicions here mentioned, it is evident that this object deserves careful scrutiny for a few years to come. The largest star of the central trio is of magnitude 9½; the other two of magnitude 13.

[1] *Month. Not.*, vol. xxxiv. p. 86. Dec. 1873.

CHAPTER III.

Variable Stars.—o Ceti.—Algol.—δ Cephei.—β Lyræ.—R Coronæ Borealis.—η Argûs.—Miscellaneous remarks.—Temporary Stars.—Notices of Stars which have disappeared.—Proper motion.—Motion of the System through space.—Summary by W. Struve.—Proper motion first suspected by Halley.—Wright's hypothesis of a Central Sun.—Revived by Mädler.—Stars which are probably Centres of Systems.

THERE are many stars which exhibit periodical changes of brilliancy: these are termed *variable* stars. About 150 stars are now known to belong to this class, and many more still are put down as 'suspected.'

One of the most interesting, as also the first that was recognised, of these curious objects, is o Ceti, or *Mira* [sc. *stella*]. It appears about 12 times in 11 years; remains at its greatest brightness for about a fortnight, when it sometimes equals in brilliancy a star of the 2nd magnitude; decreases during about 3 months, till it becomes totally invisible; remains so for about 5 months, and then gradually recovers its brilliancy during the remaining 3 months of its period. Its maximum brightness is not always the same, nor does it always increase or diminish by the same gradations; nor are the successive intervals of its maxima equal. The mean period is $331^d\ 8^h$, but it would appear from the researches of Argelander[a] that this is subject to a cyclical variation embracing 88 such periods, which has the effect of gradually lengthening and shortening alternately these periods to the extent of 25 days one way and the other. It is not improbable too that the irregularities of its maximum brilliancy are also periodical, that is to say, that at every 11th maximum the star's brightness is above the

[a] *Ast. Nach.*, vol. xxvi. No. 624. Jan. 22, 1848.

average. On Oct. 5, 1839 (the epoch of maximum for that year, according to Argelander), Mira was unusually bright, excelling α Ceti and equalling β Aurigæ. On the other hand, according to the testimony of Hevelius, between Oct. 1672 and Dec. 1676 it did not *appear at all*[b]. The average duration of the naked-eye visibility is about 18 weeks, but in 1859–60 Mira was observed with the naked eye during 21 weeks, whilst in 1868 the term was but 12 weeks.

I append a few details connected with the history of this star:—

On Aug. 13, 1596, David Fabricius noted a star in Cetus to be of the 3rd magnitude, and that in October of the same year[c] it had disappeared. 7 years later, or in 1603, Bayer affixed the letter *omicron* (o) to a star in Cetus placed exactly where the star of Fabricius had disappeared. He observed it to be of the 4th magnitude, but not comparing with his own the former observations of Fabricius he failed to make the discovery which was within his grasp.

In the beginning of Dec. 1638, Phocylides Holwarda of Franecker saw this star shining brighter than one of the 3rd magnitude. In the summer of the following year he was unable to find any trace of it, but on Oct. 7 he again perceived it; and to him may be assigned the honour of having first discovered the existence of a variable star.

In 1648 Hevelius commenced a careful series of observations, which were carried on till 1662, during which time he placed the certainty of the discovery beyond a doubt, and made a first approximation to a knowledge of the attendant circumstances[d]. In the following century, between the years 1779 and 1790, Sir W. Herschel observed this star with his wonted diligence, and materially added to our knowledge of it[e]. In more recent times the name of Argelander may be singled out as specially associated with o Ceti.

Algol, or β Persei, is a variable star of short period, which from its position may often be brought under notice. It is commonly of the 2nd magnitude: from that it descends to the

[b] Lalande, *Astronomie*. Art. 794.

[c] Kepler, *De Stellâ Novâ*, cap. xxiii. p. 115.

[d] *Historiola Miræ Stellæ*. Fol. Gedan, 1662.

[e] *Phil. Trans.*, vol. lxx. p. 338. 1780.

4^{th} magnitude in a period of about $3\frac{1}{2}^h$, and at this it remains for about 20^m. Another period of $3\frac{1}{2}^h$ then brings the star up to the 2^{nd} magnitude, at which it remains for another period of $2^d\ 13^h$, when similar changes recur. Near the epoch of maximum and minimum the variations of brilliancy proceed slowly, but at the intermediate stages they are much more rapid, and therefore more noticeable. The exact period in which all these changes take place is $2^d\ 20^h\ 48^m\ 55^s$.

The observations of Argelander, Heis, and Schmidt tend to shew that the period of Algol is less than it was in former years, but that this diminution is not uniformly progressive, inasmuch as an augmentation has now set in; and it may be inferred that future and long-continued observations will result in the discovery that this change of period is itself periodical.

The variability of Algol was discovered by Montanari in 1669 and confirmed by Maraldi in 1694: its period was determined by Goodricke in 1782, who also may be said to have re-discovered its variability [f].

δ Cephei is another variable star which derives additional interest from the fact that its position in the heavens permits frequent observation of it in England. Its period is $5^d\ 8^h\ 47^m$, counting from minimum to minimum, and its range is from mag. $3\frac{1}{2}$ to mag. $4\frac{1}{2}$. The interval between the maximum and minimum is greater than that between the minimum and maximum, the former being $3^d\ 19^h$, the latter only $1^d\ 14^h$. The variability of this star was discovered by Goodricke in 1784.

β Lyræ is a variable star, remarkable as having a double maximum and minimum within its simple period. Goodricke, the discoverer, assigned to it a period of about $6\frac{3}{8}^d$, but the more recent observations of Argelander shew that the true period is double this; or, more exactly, $12^d\ 21^h\ 53^m$—thus set forth [g]: Starting from a maximum when the star is of mag. $3\frac{1}{2}$ it reaches the first minimum of mag. 4; then follows a second maximum, and after that a second minimum, but at this second period of least light the star is fainter than before, being only equal to a $4\frac{1}{2}$ mag. Argelander further ascertained that, as in the case of *o* Ceti, the

[f] The Saxon farmer Palitzch, noted for his early detection of Halley's comet in 1758, is stated by Sir J. Herschel to have done the same thing.

[g] Argelander, *Ast. Nach.*, vol. xxvi. No. 624. Jan. 22, 1848.

period of β Lyræ is itself variable; that down to the year 1840 it was increasing, but that from that period it began to decrease, and was continuing to do so at the time the remark in question was made (1866). The annual amount of the increment gradually diminished till the stationary epoch, whence we may anticipate by analogy that now the decrement will gradually become more rapid.

The variable star R Coronæ Borealis is noticeable from the fact that on some occasions the fluctuations in brightness between the maximum and minimum epochs are so inconsiderable as to be scarcely perceptible, but that after some years of these almost insensible variations, the fluctuations become so great that at its minimum the star entirely disappears. To Argelander also we owe the knowledge of this fact. The period of this star is 323 days. At its maximum its brilliancy is that of a star of the 6th magnitude. Its variability was discovered by Pigott in 1795.

Perhaps the most remarkable variable star with which we are acquainted is η Argûs—an object unfortunately not visible in England. The following historical notes, down to 1850, were brought together by Humboldt [h]:—

As early as the year 1677, Halley, on his return from St. Helena, frequently expressed a doubt respecting the constancy of the brightness of the stars in the constellation Argo; he had especially in his mind those belonging to the prow and the deck, the magnitudes of which had been indicated by Ptolemy. But the uncertainty of the ancient designations, the numerous variations of the manuscript of the *Almagest*, and especially the difficulty of obtaining exact evaluations of the brightness of the stars, did not permit him to transform his suspicions into a certainty. In 1677 he classed η Argûs among the stars of the 4th magnitude; in 1751 La Caille found it to be of the 2nd magnitude. Subsequently it resumed its original appearance, for Burchell, during his residence in South Africa from 1811 to 1815, noted it to be of mag. 4. From 1822 to 1826 it appeared to be of mag. 2 to Brisbane in New South Wales, and Fallows at the Cape. In 1827 Burchell, then residing at St. Paul in Brazil, found it to be of mag. 1, and almost as bright as α Crucis. A year after-

[h] Quoted in Arago's *Pop. Ast.*, vol. i. p. 258, Eng. ed.

-wards it had decreased to the 2nd magnitude. To this class it still belonged on Feb. 29, 1828, when Burchell observed it at Goyaz, and it is under this magnitude that Johnson and Taylor have entered it in their catalogues, 1829–1833. When Sir J. Herschel was at the Cape between 1834 and 1837 he placed it constantly between mags. 2 and 1: but on Dec. 16 in the latter year, whilst scrutinising the stars lying around the great nebula in Argo, his attention was attracted towards a strange phenomenon—η Argûs, which he had so frequently observed on former occasions, had so rapidly increased in brightness as to equal α Centauri, surpassing every other star in the heavens except Canopus and Sirius. Its maximum brilliancy occurred on or about Jan. 2, 1838. Thenceforward it began to fade away; in April, however, it was still as bright as Aldebaran. This diminution went on till April 1843, though at no time did the star fall below the 1st magnitude. In April a rapid augmentation set in, and according

Fig. 148.

DIAGRAM REPRESENTING THE LIGHT-CURVE OF η ARGUS. (*Loomis.*)

to the observations of Mackay at Calcutta and Maclear at the Cape, η Argûs surpassed Canopus and scarcely fell short of Sirius in brilliancy. Under date of Feb. 1850 Lieut. Gilliss, then in Chili, reported η Argûs to be of a reddish yellow colour, somewhat darker than that of Mars, and very nearly as bright as Canopus.

Since 1850 much has been done, especially by E. B. Powell and Tebbutt [i], towards elucidating the anomalous irregularities (as they were long deemed to be) in the light of η Argûs, and a diagram submitted in 1869 to the Royal Astronomical Society by Loomis [k] seems to make the matter fairly clear. On the whole we are justified in assuming that η Argûs varies from mag. 1 to mag. 6 during a period of about 70 years. The maximum phase however

[i] *Month. Not.*, vol. xxvi. p. 83, Jan. 1866; and vol. xxviii. p. 266, Oct. 1868.

[k] *Month. Not.*, vol. xxix. p. 298, May 1869.

is complicated, and consists of three maxima which jointly occupy about 25 years of the 70, during which sub-period the oscillations are restricted to mags. 1 and 2, this sub-period falling as near as may be in the mid-interval between every 6th mag. minimum of the star.

Some remarkable circumstances connected with η Argûs and the nebula surrounding it will more appropriately be related in the next chapter.

Several explanations have been offered to account for the variability of stars, but all are unsatisfactory because the irregularities of the periods offer a bar to any hypothesis which supposes a regular series of changes. Boulliaud, in the case of ο Ceti, ascribed its variability to its being a globe of irregular luminosity rotating on an axis, by which different portions of the differently illuminated surface were successively turned towards us [l].

Pigott suggested that an opaque body revolving round a variable star as its primary, whose light would be cut off from time to time after the manner of an eclipse of the Sun, would produce the phenomenon [m].

The following are some of the more prominent periodic stars visible to the naked eye:—

Name.	R. A. 1870.			Decl. 1870.		Period.	Changes of Magnitude.	
	h.	m.	s.	°	′	d.	From	to
β Persei	2	59	43	+40	27·2	2·86	2½	4
δ Cephei	22	24	21	+57	45·0	5·36	3·7	4·8
η Aquilæ	19	45	51	+ 0	40·4	7·17	3·6	4·7
β Lyræ	18	45	17	+33	12·7	12·91	3½	4½
α Herculis	17	8	43	+14	32·4	88·5	3·1	3·9
ο Ceti	2	12	47	− 3	34·1	330·0	2	0
υ Hydræ	13	22	37	−22	36·4	436·0	4	10
η Argûs	10	40	2	−59	0·1	70 years	1	6

Hind has called attention to the fact that variable stars, especially the smaller ones, are frequently of a ruddy colour. The

[l] *Ad Astronomos monita duo.* 4to. Paris, 1667.
[m] *Phil. Trans.*

same observer has noticed that when at their minimum they appear surrounded by a kind of fog. Arago remarks that if this latter opinion should turn out to be well founded it might give us a clue, none other than that the diminution of brilliancy is due to the interference of clouds which cut off a part of the stellar light[n]. It may here be noted as an undoubted fact that with respect to red variable stars as they lose light they gain colour and *vice versâ*, which circumstance favours the hypothesis that absorption of light is the cause of the phenomenon.

Somewhat similar in character to those stars which we have just been considering, are the *temporary stars*—stars which suddenly blaze out in the heavens and after a while fade away. The first on record was observed by Hipparchus. Pliny informs us that it was the appearance of this star which induced Hipparchus to construct his catalogue of stars, the first which was ever executed. This statement was by many regarded as a fiction, but E. Biot found that a new star in Scorpio is recorded in the Chinese chronicles under the date of 134 B.C., so that there is no longer any ground for rejecting Pliny's statement. It may be added that the date commonly assigned to Hipparchus's catalogue is 125 B.C.

Brilliant stars appeared in or near Cassiopeia in the years 945, 1264, and 1572. The last was a very remarkable one, and a most elaborate and graphic account of it is given by Tycho Brahe[o], some extracts from which will be found in Humboldt's *Cosmos*. The substance of his description is as follows: The star lasted from November 1572 to March 1574, or 17 months. It was brighter than Sirius, and rivalled Venus. Its colour was successively white, yellow, red, and white again, and it remained stationary all the while in the position which it occupied when discovered. It has been conjectured, and with great plausibility, that the above 3 stars are identical, being apparitions of a variable star of long period; and there exists at this moment within 1′ of the place assigned by Argelander to Tycho's star, a small star sensibly variable in its light, according to the observations of Hind and Plummer in 1873[p].

Temporary stars of considerable brilliancy shone forth in 1604

[n] *Pop. Ast.*, vol. i. p. 260, Eng. ed.

[o] *Progymnasmata*, lib. i. The writer devotes 478 closely-printed pages to this one star!

[p] *Month. Not.*, vol. xxxiv. p. 168. Feb. 1874.

and 1670. The former appeared in the constellation Ophiuchus, and became nearly as bright as Venus; it lasted 12 months or more[q]. The latter appeared in Cygnus, and attained the 3rd magnitude; it lasted altogether 2 years, but faded away and then blazed out again more than once before its final disappearance[r].

On April 28, 1848, a new star of the 5th magnitude was seen by Hind in Ophiuchus[s]. It rose to the 4th magnitude a few weeks later; subsequently its light diminished, and now it is usually of the 11th or 12th magnitude[t].

I quote from Sir J. Herschel the following remark:—"It is worthy of especial notice, that all the stars of this kind on record, of which the places are distinctly indicated, have occurred, *without exception*, in or close upon the borders of the Milky Way, and that only within the *following* semi-circle, the *preceding* having offered no example of the kind[u]."

Numerous instances are on record of stars formerly known which are now not to be found[x], and *vice versâ* of new stars appearing which were never before noticed. There once were stars to the number of 4 in Hercules, 1 in Cancer, 1 in Perseus, 1 in Pisces, 1 in Hydra, 1 in Orion, and 2 in Coma Berenices, which seem now to have disappeared. Several stars in the catalogue of Ptolemy do not appear in that of Ulugh-Beigh; 6 of these were near Piscis Australis, and as 4 were of the 3rd magnitude, Baily concludes that they were visible in Ptolemy's time, but disappeared before the time of Ulugh-Beigh. Many discrepancies have, no doubt, arisen from mistaken entries, yet there are other instances in later times which it is quite out of the question to explain in this way. Thus 55 Herculis, mag. 5, was observed by Sir W. Herschel in 1781 and 1782, but 9 years afterwards it could not be found, and has not been seen since. In May 1829 Sir J. Herschel missed one of De Zach's stars in Virgo. Montanari remarked, in 1670, as follows:—"There

[q] Kepler, *De Stellâ novâ in pede Serpentarii.*

[r] *Phil. Trans.*, vol. v. p. 2087 *et seq.*, 1670; also vol. vi. p. 2197 *et seq.*, 1671.

[s] *Month. Not.*, vol. viii. p. 146. April 1848.

[t] Arago and other writers say that this star *disappeared;* but Hind has expressly stated this to be incorrect. *Month. Not.*, vol. xxi. p. 232. June 1861. It is now regularly included in catalogues of variable stars.

[u] *Outlines of Ast.*, p. 605.

[x] Sir W. Herschel, *Phil. Trans.*, vol. lxxiii. pp. 250–3. 1783.

are now wanting in the heavens 2 stars of the 2nd magnitude, in the stern and yard of the Ship Argo. I and others observed them in the year 1664, upon the occasion of the comet that appeared that year. When they first disappeared, I know not; only I am sure that on April 10, 1668, there was not the least glimpse of them to be seen[y]."

Two assumptions may here be stated which I cannot but think will eventually be established: viz. that (1) all the "temporary" stars on record, and (2) such of the "missing" stars as do not depend on errors of observation—will be found to be ordinary "variable" stars. Many years may elapse before it becomes possible to confirm fully these surmises.

To the naked eye the stars appear to preserve the same positions relatively to one another from year to year, and hence they have been called the *fixed stars;* but, as I have already mentioned, this is not strictly true with many stars, for careful observations shew that they are endued with a *proper motion* of their own through space. Inasmuch, however, as in no case does this proper motion exceed a few seconds per annum, there is no essential impropriety in retaining the designation "fixed stars," or, as Sir John Herschel put it, "Motions which require whole centuries to accumulate before they produce changes of arrangement such as the naked eye can detect, though quite sufficient to destroy that idea of mathematical fixity which precludes speculation, are yet too trifling, as far as practical applications go, to induce a change of language, and lead us to speak of the stars in common parlance as otherwise than fixed. Small as they are, however, astronomers, once assured of their reality, have not been wanting in attempts to explain and reduce them to general laws."

C. P. Smyth, from an investigation of the history of the star 793 B.A.C. Ceti, appears to believe in the existence of such a thing as periodical proper motion, that is to say, that the amount of a star's proper motion may vary by cycles[z]. If this idea should turn out to be, to any considerable extent, well founded, interesting discoveries may be looked for at some future time in this branch of sidereal astronomy.

[y] *Phil. Trans.*, vol. vi. p. 2202. 1671.
[z] *Month. Not.*, vol. xxxv. p. 356. May 1875.

Amongst the stars whose annual proper motion is considerable may be mentioned[a]—

		″
1830 Groombridge Ursæ Majoris	.. .. ..	7·03
61 Cygni	.. ..	5·12

The first astronomer to whom the idea of a proper motion of the stars presented itself was Halley. Comparing the ancient places of the 3 important stars Sirius, Arcturus, and Aldebaran, with his own places determined in 1717, and making every allowance for variation in the obliquity of the ecliptic, he found discordances in latitude amounting to 37′, 42′, and 33′ respectively. Thus he arrived at his surmise as to the existence of proper motion: scientific proof had yet to follow. This was obtained in 1738 by James Cassini, who ascertained that Arcturus had suffered a displacement of 5′ in 152 years, whilst the neighbouring star η Boötis had not been similarly or at all affected. Cassini further discovered the existence of proper motion in longitude, and it was remarked by Fontenelle, "There is a star in the Eagle (α) which, if all things continue their present course, will, after the lapse of a great number of ages, have to the West another star which at present appears to the East of it."

The existence of stellar proper motion being beyond question, it was a natural step forward to seek to determine what it involved. Sir W. Herschel entered upon an inquiry in 1783, and by carefully classifying all the proper motions then known he was led to infer that the solar system was moving towards a point indicated by R.A. $17^h\ 8^m$, Decl. $+25°$. This point is near the star λ Herculis. To review all that has been done in this department of physical astronomy would demand more space than it would be convenient for me to give[b]: suffice it, therefore, to say that several recent calculators, employing a considerable number of stars, both Northern and Southern, have one and all confirmed not only Sir W. Herschel's general deduction, but likewise his conclusion as to the precise point, to within a very few degrees of arc; or, in the words of W. Struve (after a careful examination of the researches of MM. Argelander, O. Struve, and C. A. F. Peters): "*The motion of the solar system in space is directed to*

[a] See papers by Lynn, *Month. Not.*, vol. xxx. p. 203, June 1870, vol. xxxiii. p. 103, Dec. 1873, and a much older one by Baily in *Mem.* R.A.S., vol. v. p. 158, 1833.

[b] See Grant's *Hist. Phys. Ast.*, p. 555 *et seq.*

a point in the celestial sphere situated on the right line which joins the 2 stars of the 3rd magnitude π and μ Herculis, at ¼ of the apparent distance between these stars measured from π Herculis. The velocity of the motion is such that the Sun, with the whole cortège of bodies depending on him, advances annually in the direction indicated, through a space equal to 1·623 radii of the terrestrial orbit[c]."

Spectroscopic observations by Huggins, of an ingenious but elaborate character, confirm the main features of these conclusions[d].

As connected with the matter which has just been discussed, a passing allusion must be made to the Central Sun hypothesis, first started by Wright in 1750, and revived by Mädler a few years since[e]. This theory simply supposes the existence of some central point around which the Sun, with its vast attendant *cortége* of planets and comets, revolves in the course of millions of years. Mädler thinks he has sufficient ground for believing that this point is situated in or near the Pleiades, or, more exactly, at the star Alcyone (η Tauri). Grant very sensibly remarks: "It is manifest that all such speculations are far in advance of practical astronomy, and therefore they must be regarded as premature, however probable the supposition on which they are based, or however skilfully they may be connected with the actual observation of astronomers." Vague ideas of the motion of the solar system around some common centre are to be found in Lucretius[f]: it was thought that but for such motion all celestial objects must have collapsed and formed a chaos.

There are some stars which Sir W. Herschel was disposed to consider to be in a great measure out of the reach of the attractive force of other stars, and as probable centres of extensive systems like our own. Among them are:—

Vega (α Lyræ).	Bellatrix (γ Orionis).
Capella (α Aurigæ).	Menkab (α Ceti).
Arcturus (α Boötis).	Schedir (α Cassiopeiæ).
Sirius (α Canis Majoris).	Algorab (δ Corvi).
Canopus (α Argûs).	Propus (ι Geminorum).
Markab (α Pegasi).	

[c] *Etudes d'Ast. Stell.*, p. 108.

[d] See *Ast. Reg.*, vol. x. p. 165. July 1872. *Proc. Roy. Soc.*, vol. xx. p. 386. June 1872.

[e] In his *Die Centralsonne*, 4to. Dorpat. 1846.

[f] *De Rer. Nat.*, lib. i.

The twinkling, or scintillation[g], of the stars is a phenomenon which requires to be briefly noticed. The effect is too well known to need description, but the cause is involved in much obscurity, though it is referred by most observers to the interference of light[h]. Many ascribe it more immediately to the varying refrangibility of the atmosphere, and this latter theory has much to recommend it.

A quiescent condition of the air is unfavourable to the manifestation of twinkling. And in general the phenomenon is more marked with stars near the horizon (and therefore seen through dense strata of air) than with stars near the zenith; and at the surface of the Earth than in mountainous districts at high elevations where the air is more rarefied—all of which facts point out the atmosphere as an influential agent. In confirmation of this is Humboldt's statement that in the pure air of Cumana twinkling ceased after the stars attained an elevation of 15° above the horizon. Dunkin gives the useful caution that "This law of twinkling, according to the altitude of the object, is not however universal, for several of the principal fixed stars, on account of the nature and peculiarity of their own light, vary considerably in the intensity of their scintillations independently of their position in the heavens. Procyon and Arcturus are known to twinkle much less than Vega, the brilliant bluish-white star in Lyra[i]." According to Dufour, red stars twinkle less than white ones[k]. Liandier, from repeated observation, says that he is convinced that twinkling is due to disturbances of the atmosphere, brought about by winds and currents of air. The greater the twinkling, the easier it is to see faint stars[l].

[g] *Scintilla*, a spark of fire.

[h] *Eng. Cycl.*, Arts and Sciences Div., art. *Twinkling*.

[i] *The Midnight Sky*, p. 191.

[k] *Month. Not.*, vol. xviii. p. 51. Dec. 1857.

[l] A summary of some interesting spectroscopic observations of Twinkling Stars made by Respighi will be found in *Month. Not.*, vol. xxxii. p. 173, Feb. 1872, and should be consulted by the curious reader.

CHAPTER IV.

CLUSTERS AND NEBULÆ.

Arranged in three classes.—Five kinds of Nebulæ.—The Pleiades.—The Hyades.—Mentioned by Homer.—Præsepe.—Opinion of Aratus and Theophrastus.—Coma Berenices.—List of Clusters.—Annular Nebulæ.—Elliptic Nebulæ.—Spiral Nebulæ.—Planetary Nebulæ.—Nebulous stars.—List of irregular Clusters.—Notes to the objects in the list.—The Nubeculæ major and minor.—List of Nebulæ in Sir J. Herschel's Catalogue of 1864.—Historical statement relating to the observation of Nebulæ and Clusters.

IF we examine the heavens on a clear evening when the Moon is not shining, we shall find here and there groups of stars which seem to be compressed together in such a manner as to present a hazy cloud-like appearance; these are termed *clusters* and *nebulæ*, and may be conveniently classed as follows:—

1. Irregular groups, visible more or less to the naked eye.
2. Clusters resolvable into separate stars with the aid of a telescope.
3. Nebulæ, for the most part irresolvable with the telescopes which we at present possess.

The objects forming the 3rd class may in their turn be subdivided into—

i. Annular nebulæ.
ii. Elliptic nebulæ.
iii. Spiral nebulæ.
iv. Planetary nebulæ.
v. Nebulous stars.

Of the 1st class there are several examples to be found, with all of which the reader is probably more or less familiar. The

cluster of the *Pleiades*, in Taurus, is doubtless the best known*. When examined *directly* few persons can see more than 6 stars, but by turning the eye *sideways*, more may be seen. Thus, Miss Airy has noted 12, and Möstlin, according to Kepler, 14. Between 50 and 60 stars, to say the least of it, are visible in a telescope. The following are some of the different estimations:—

Kepler	32	Hooke	78
La Hire	64	De Rheita	118

Fig. 149.

The Pleiades, in Taurus. Naked-eye View. (*Miss Airy.*)

The most brilliant star in the group is *Alcyone*, or η Tauri, of the 3rd magnitude; next in order come *Electra* and *Atlas*, of the 4th; *Maia* and *Taygeta*, of the 5th; *Pleione* and *Celeno*, which are between the 6th and 7th; *Asterope*, between the 7th and 8th; and finally, a great number of smaller stars.

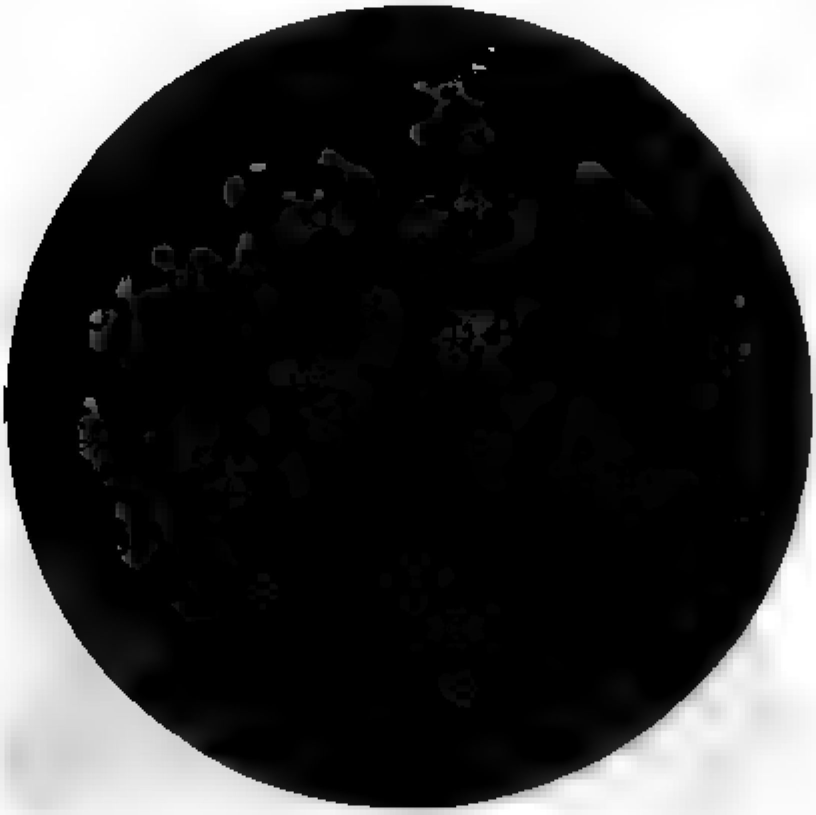
The *Hyades* is another loose group in Taurus, near Aldebaran, and somewhat similar in character to the cluster near λ Orionis,

* The Pleiades and Hyades are among the few stars mentioned by Homer. (*Odyssey*, lib. v. ver. 270.) The engraving by Jeaurat is taken from *Hist. de l'Acad. Royale des Sciences*, 1779, p. 505; published in 1782.

neither of them of much account as telescopic objects, the stars being too scattered.

Fig. 150.

S

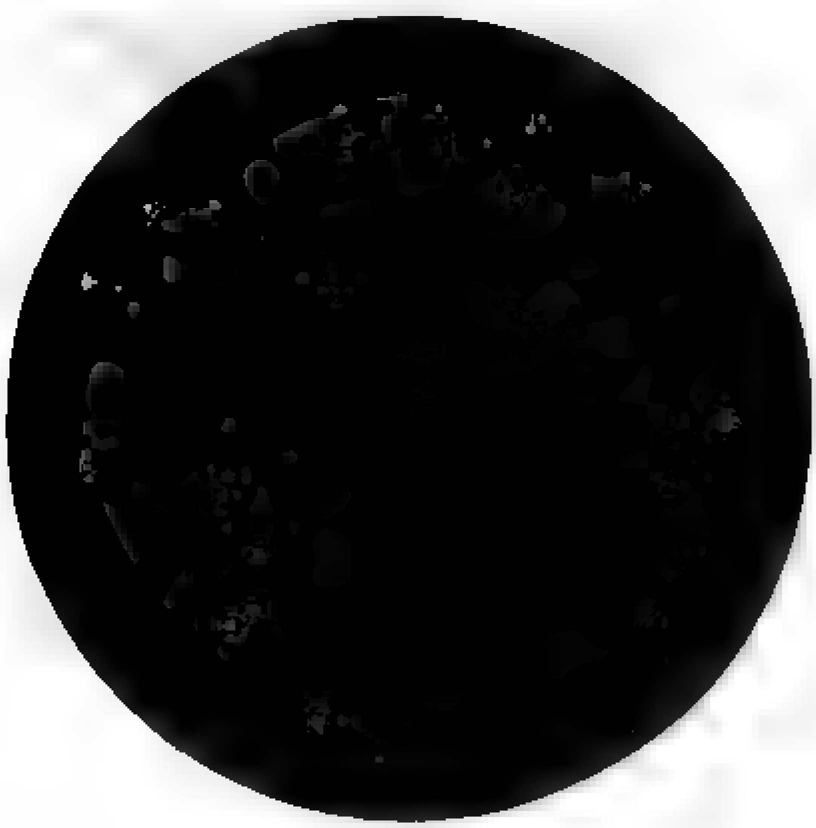


N

The Pleiades, in Taurus. Telescopic View. (*Jeaurat.*)

Præsepe, or the "Bee-hive," in Cancer, is one of the finest objects of this kind for a small telescope; it is an aggregation

Fig. 151.

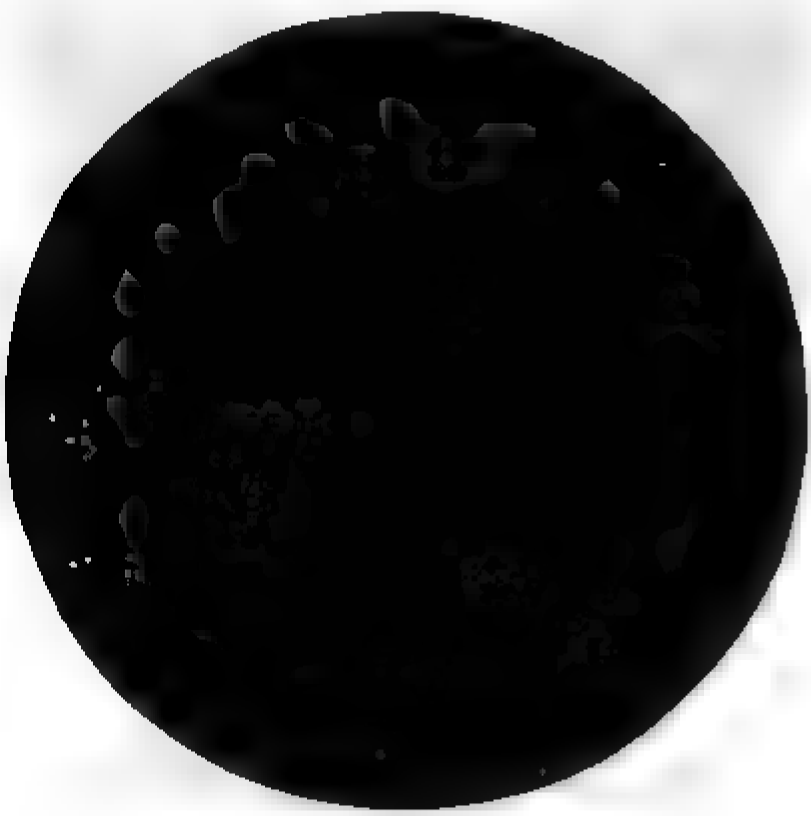


The Hyades, in Taurus.

of little stars, which has long borne the name of a nebula, its components not being visible to the naked eye; indeed, before the invention of the telescope, it must have been the only recognised one. Aratus[b] and Theophrastus[c] tell us that its becoming dim and ultimately disappearing was regarded as an indication of rain.

The group forming the constellation *Coma Berenices* has fewer stars, but they are of larger size and more diffused. As Webb well remarks, "This is a gathering of small stars, which obviously at a sufficient distance would become a nebula to the naked eye."

Fig. 152.



Praesepe, in Cancer.

In reference to globular clusters and the hypothesis that they are formed of stars evenly distributed in space, Guillemin remarks: "But the increase of brightness from the border to the centre is often more rapid than the hypothesis of an equal distribution of the stars in the interior will sanction. It has been held therefore that besides the apparent or purely optical condensation, there exists a real condensation, which is produced doubtless by the

[b] *Diosemeia*, ver. 160. See Lamb's translation, p. 70, where the passage is very prettily rendered into English verse.

[c] *De Signis Pluviarum*, p. 419. Heinsius's ed. Lugd. Batavor.

influence of the central forces, resulting from the separate attractions of each of the suns which compose these systems[d]."

The following objects will serve as representatives of the 2nd class[e] :—

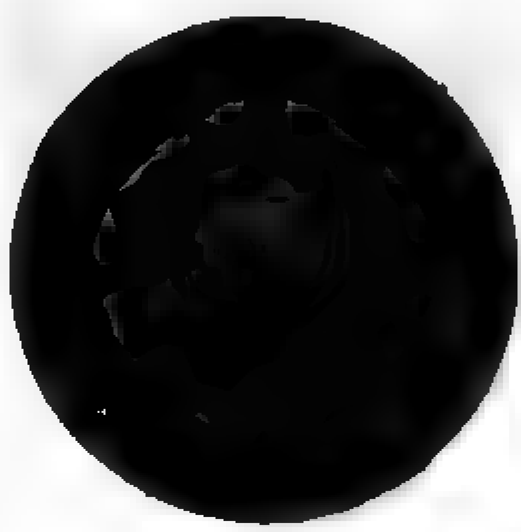
No.	Name.			H.'s Cat. of 1864.	R. A. 1870.			Decl. 1870.	
					h.	m.	s.	°	′
1	31 H VI Cassiopeiæ ..		..	392	1	37	10	+ 60	35·4
2	33 H VI Persei	..	..	512	2	9	57	+ 56	32·9
3	35 M Geminorum	..	..	1360	6	0	49	+ 24	20·7
4	3 M Canum Venaticorum ..			3636	13	36	8	+ 29	1·8
5	5 M Libræ ..	..	..	4083	15	11	57	+ 2	34·6
6	80 M Scorpii ..	..	..	4173	16	9	17	− 22	39·1
7	13 M Herculis	..	..	4230	16	37	3	+ 36	42·5
8	92 M Herculis	..	..	4294	17	13	15	+ 43	15·8
9	22 M Sagittarii	..	..	4424	18	28	28	− 24	0·0
10	11 M Antinoi	..	..	4437	18	44	9	− 6	25·5
11	15 M Pegasi ..	..	..	4670	21	23	39	+ 11	35·2
12	2 M Aquarii	..	..	4678	21	26	43	− 1	24·0

No. 1 is a somewhat conspicuous object, that is to say, it is readily visible with a telescope of 2 inches aperture.

No 2 lies in immediate proximity to 34 H VI Persei, and the two objects are frequently taken together and spoken of as "the cluster in the sword-handle of Perseus." These two clusters have been well termed by Webb "gorgeous," and by Smyth as "affording together one of the most brilliant telescopic objects in the heavens."

No. 4 was described by Smyth as "a brilliant and beautiful globular congregation of not less than 1000 small stars." There

Fig. 153.



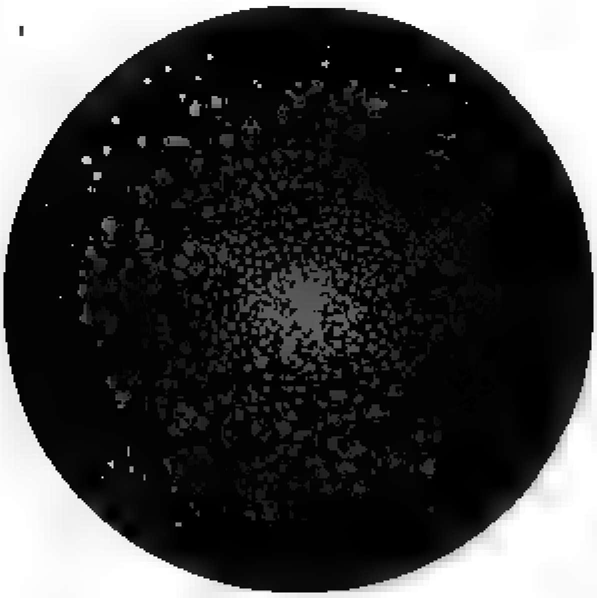
3 M CANUM VENATICORUM.
(*Smyth.*)

[d] *The Heavens*, Eng. ed., p. 377.

[e] Most of the clusters and nebulæ engraved in this chapter but not separately mentioned will be found alluded to in the Catalogue of Celestial Objects in Chapter VIII (*post*).

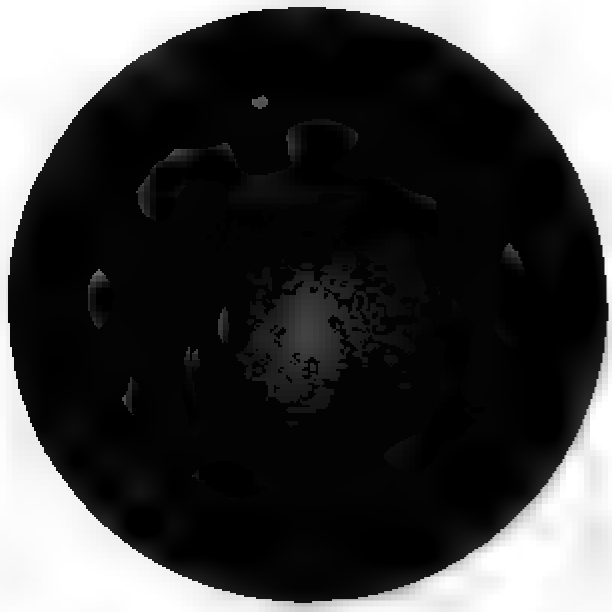
is a sensible concentration of stars near, but not actually at, the centre of the cluster.

Fig. 154.



5 M Libræ.
(*Sir J. Herschel.*)

Fig. 155.



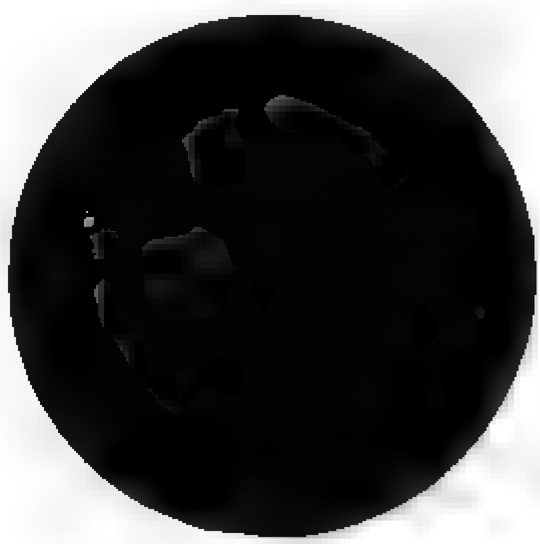
13 M Herculis.
(*Sir J. Herschel.*)

No. 5 (5 M Libræ), in the words of Webb, is a "beautiful assemblage of minute stars greatly compressed in centre." Sir W.

Fig. 156.

80 M Scorpii.
(*Smyth.*)

Fig. 157.



92 M Herculis.
(*Smyth.*)

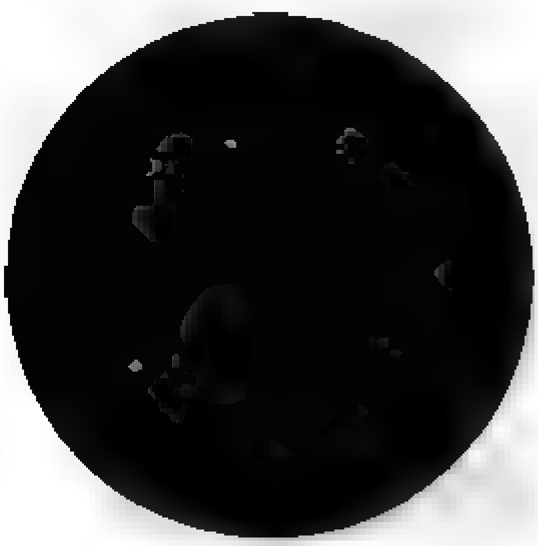
Herschel with his 40-ft. reflector made out about 200 stars; Sir J. Herschel notes that the stars range between mags. 11–15.

No. 6 (80 M Scorpii) much resembles a telescopic comet. Sir W. Herschel called it the richest and most condensed mass of stars

in the firmament. Near its centre, or more likely, as Webb judiciously suggests, "between it and us," is a remarkable variable star, particulars of the sudden apparition of which in 1860 will be found elsewhere (see Chap. V, *post*).

No. 7 (13 M Herculis) is commonly regarded as the finest of the globular clusters. Smyth called it "an extensive and magnificent mass of stars, with the most compressed part densely compacted and wedged together under unknown laws of aggregation,"—a very good description. Sir J. Herschel spoke of thousands of stars and "hairy-looking curvilinear branches," which features the Earl of Rosse interpreted as indicative of a spiral tendency; he also perceived several dark rifts in the interior of the cluster. Huggins finds the spectrum to be continuous. This cluster was discovered

Fig. 158.



22 M SAGITTARII.
(*Smyth.*)

Fig. 159.

11 M ANTINOÏ.
(*Smyth.*)

by Halley in 1714, and is visible in *one sense* with any telescope, however small.

No. 8 (92 M Herculis) is a fine globular cluster, inferior however to the preceding. It has a marked central condensation, and exhibits a continuous spectrum.

No. 9 (22 M Sagittarii) is a fine globular cluster, so situated that in England it is rarely possible to do justice to it. Webb remarks that this object is "interesting from the visibility of the components (the largest, 10 and 11 mags.), which makes it a valuable object for common telescopes, and a clue to the structure of more distant or difficult nebulæ."

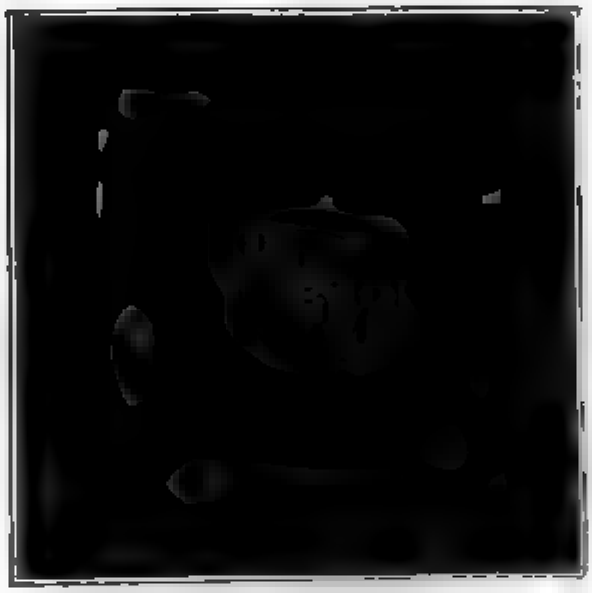
No. 10 (11 M Antinoï) is an interesting cluster of uncommon

form. Smyth likened it to a flight of wild ducks—a simile more appropriate than many of those met with in astronomical writings,

Fig. 160.

15 M Pegasi. (*Smyth.*)

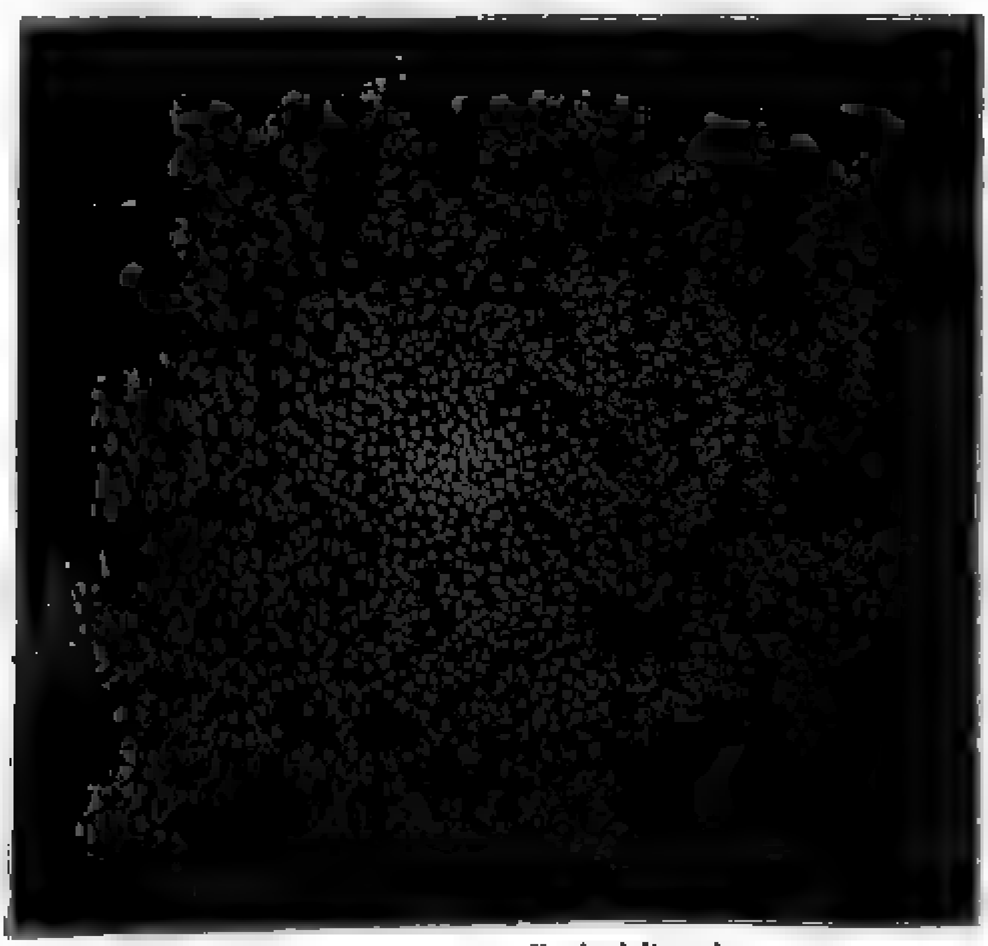
Fig. 161.



2 M Aquarii. (*Sir J. Herschel.*)

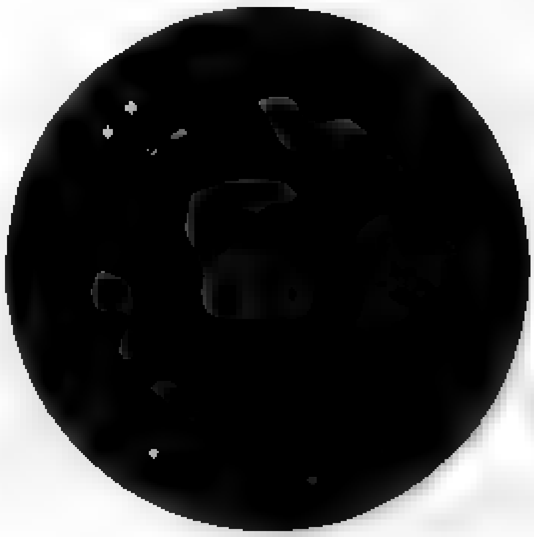
which it may be fairly said often abound in wordy exaggerations. Three stars of mag. 8 help to enhance the beauty of the field.

Fig. 162.



2 M. Aquarii. (*Earl of Rosse*)

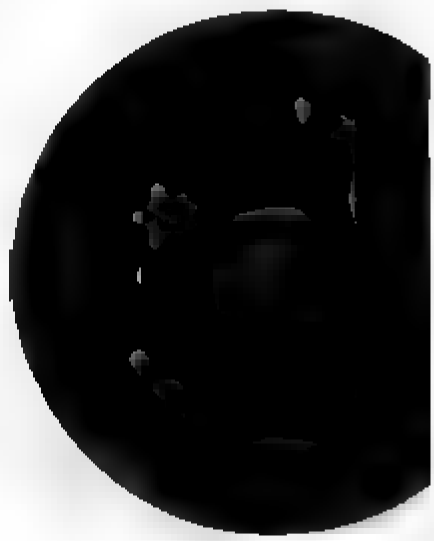
Figs. 163–168. **Plate XXII**



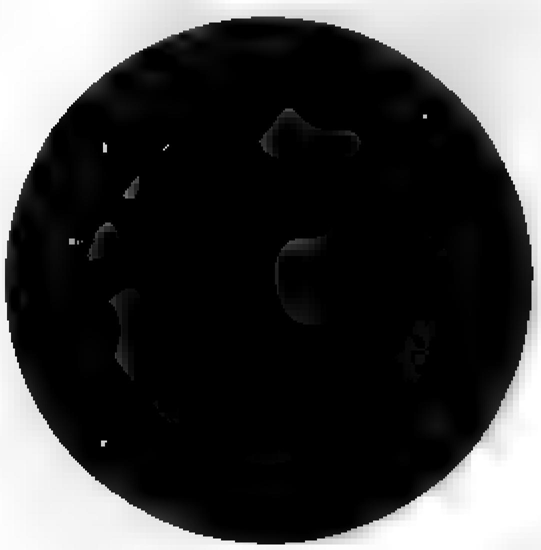
14 M Ophiuchi.

30 M Capricorni.

52 M Cephei.



56 M Lyræ.



64 M Comæ Berenicis.

67 M Cancri.

RESOLVABLE CLUSTERS.

(*Drawn by Smyth.*)

No. 11 (15 M Pegasi) is a moderately bright and resolvable cluster. Large apertures are required to make it worthy of much attention.

No. 12 (2 M Aquarii) is with small telescopes a round nebula exhibiting, in Webb's words, "a granulated appearance, the precursor of resolution." The truth of this remark will become more manifest if we compare Lord Rosse's figure with Sir J. Herschel's. Sir John compared this object to a heap of fine sand, and considers it to be composed of thousands of 15-mag. stars, a statement which is probably a little over-drawn.

I now pass on to another order of objects which present themselves much less clearly to our eyes than the brilliant clusters enumerated above—the *nebulæ* properly so called. Some of them are resolvable in large telescopes, but the greater number defy the utmost efforts made to separate them into component stars, though probably most of them are stellar. They are usually faint misty objects, many of them not unlike comets or specks of luminous fog. It has been found convenient to subdivide them into five classes, which I shall now proceed to consider briefly.

Of annular nebulæ the heavens afford only four examples. The most remarkable one occurs in Lyra, R.A. $18^h\ 48^m\ 21^s$, Decl.

Fig. 169.

(*Sir J. Herschel.*)

Fig. 170.

(*Earl of Rosse.*)

The Annular Nebula 57 M Lyræ.

+32° 51′ (Messier's 57th: 4447 H). It is situated about midway between the stars β and γ, and may be seen with a telescope of moderate power, a statement which can be made of no other annular nebula[f]. Sir J. Herschel, in his description of it, said:

[f] As the nebula appeared to me on Sept. 23, 1864, in an 8¼-in. refractor, the difference between the luminosity of the central and marginal portions of the nebula was by no means considerable.

"It is small and particularly well defined, so as to have more the appearance of a flat oval solid ring than of a nebula. The axes of the ellipse are to each other in the proportion of about 4 to 5, and the opening occupies about half, or rather more than half, the diameter. The central vacuity is not quite dark, but is filled in with faint nebula like a gauze stretched over a hoop. The powerful telescopes of Lord Rosse resolve this object into excessively minute stars, and shew filaments of stars adhering to its edges[g]." Chacornac also, with a great 2½-ft. reflector by Foucault, resolved this nebula into stars. Yet, in contradiction to these circumstantial details, Huggins claims that his spectroscope shews the whole to be gaseous—probably nitrogen.

Other annular nebulæ will be found as follows:—

No.	Name.	H.'s Cat. of 1864.	R. A. 1870.	Decl. 1870.
			h. m. s.	° ′
1	4290 H Scorpii	4290	17 13 23	− 38 20·8
2	11 ℍ IV Scorpii	4302	17 21 26	− 23 38·5
3	13 ℍ IV Cygni	4565	20 11 10	+ 30 10·5

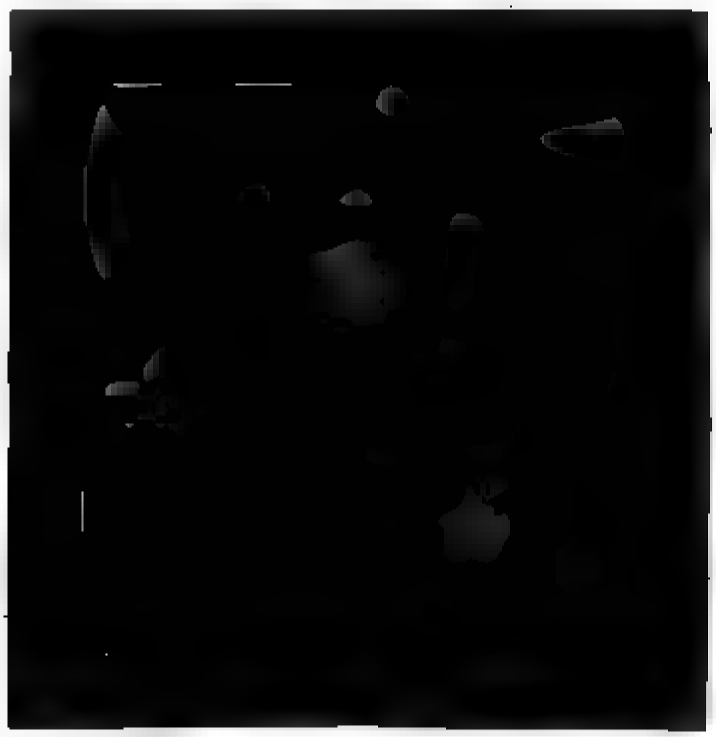
Elliptic nebulæ of various degrees of eccentricity are not uncommon; the well-known "Great Nebula in Andromeda," R.A. $0^h\ 35^m\ 42^s$, Decl. + 40° 33′·5 (Messier's 31[st] : 116 H), is an object of this kind. Its ellipticity is considerable; it is likewise very long, and has a bright central condensation sufficient to make it visible to the naked eye. A drawing by G. P. Bond portrays this nebula under an aspect differing much from that which it is commonly recognised as possessing. That observer traced it to a length of 4° and to a breadth of 2½°, and was the first to draw attention to the two curious black streaks, or longitudinal vacuities, which run nearly parallel to the major axis of the oval on the south side. Telescopes of large size are required to shew these and other details mentioned by the American ob-

[g] *Outlines of Ast.*, p. 644.

No.	Name.	H.'s Cat. of 1864.	R. A. 1870.	Decl. 1870.
			h. m. s.	° ′
1	1 H V Ceti	138	0 41 8	− 26 0·4
2	3706 H Centauri	3706	13 49 58	− 39 20·7
3	4419 H Draconis	4419	18 25 7	+ 64 54·6

The discovery of *spiral* or *whirlpool* nebulæ is due to the late Earl of Rosse. The best known is in the constellation Canes Venatici,

Fig. 172.



THE SPIRAL NEBULA 51 M CANUM VENATICORUM.
(*Smyth.*)

R.A. $13^h\ 24^m\ 20^s$, Decl. + 47° 51·8′ (Messier's 51st : 3572 H). To Sir J. Herschel it presented the appearance of a large and bright globular cluster, surrounded by a ring at a considerable distance from the globe, which varied very much in brightness in its different parts, and through about two-fifths of its circumference was subdivided as if into 2 laminæ, one of which appeared turned up towards the eye out of the plane of the rest. Near it (at about a radius of the ring distant) is a "small bright round nebula[1]." In Lord Rosse's telescope the aspect of this object

[1] *Outlines of Ast.*, p. 649.

(Sir J. Herschel.) (Earl of Rosse.)

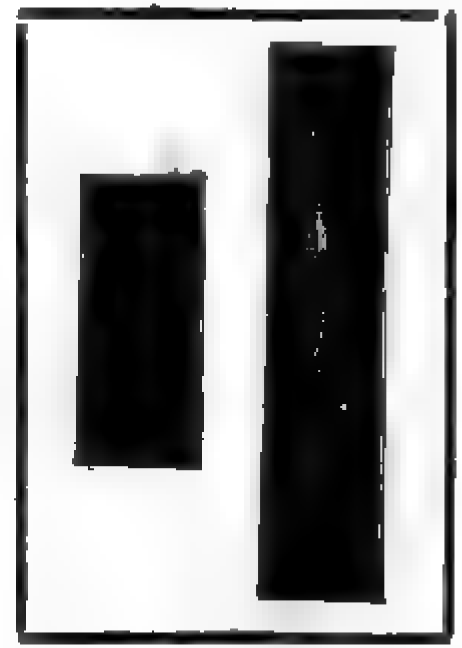
NEBULA, 65 M LEONIS.

R.A. $11^h\ 12^m\ 8^s$, Decl. + 13° 47·9′.

NEBULA, 4058 H DRACONIS.

R.A. $15^h\ 2^m\ 52^s$, Decl. + 56° 16·0′.

(Earl of Rosse.)



(Sir J. Herschel.) (Earl of Rosse.)

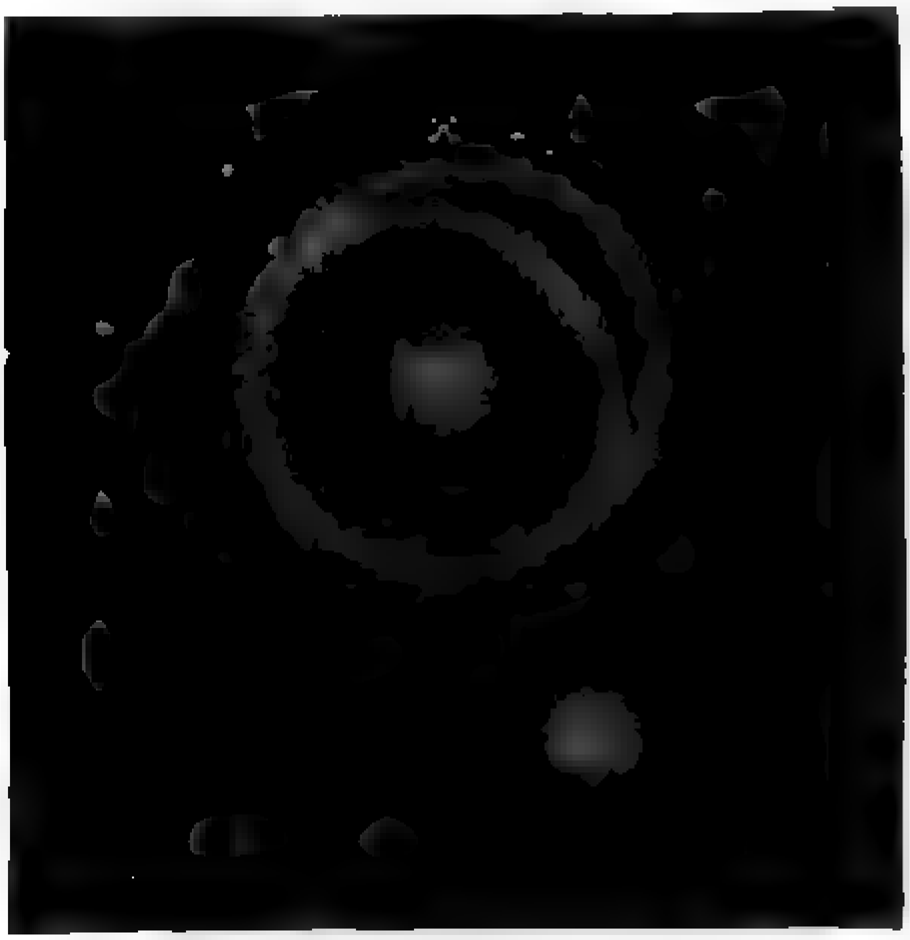
NEBULA, 3165 H COMÆ BERENICES.

R.A. $12^h\ 35^m\ 51^s$, Decl. + 33° 15·3′.

VARIOUS NEBULÆ.

is entirely altered. The ring passes into a distinct spiral coil of nebulous matter, and the outlying portion is seen to be connected with the main mass by a curved band, the whole shewing indications of resolvability into stars. A small telescope utterly fails

Fig. 178.



THE SPIRAL NEBULA 51 M CANUM VENATICORUM.
(*Sir J. Herschel.*)

to grasp any of these features. All it can do is to exhibit a misty spot of light. Huggins finds the spectrum to be non-gaseous.

Other spiral nebulæ will be found as follows:—

No.	Name.	H.'s Cat. of 1864.	R.A. 1870.	Decl. 1870.
			h. m. s.	° ′
1	33 M Piscium	352	1 26 30	+ 29 59·3
2	57 ♅ I Leonis	1861	9 24 49	+ 22 4·1
3	99 M Virginis	2838	12 12 12	+ 15 8·0
4	55 ♅ I Pegasi	4892	22 58 26	+ 11 37·5

Planetary nebulæ received their name from Sir W. Herschel on

account of their resembling in form the larger planets of our system. They are either circular or slightly elliptical; some have well-defined outlines; in others the edges appear hazy; they are throughout uniformly bright, without any traces of nuclei. One

Fig. 179.

The Spiral Nebula 51 M Canum Venaticorum.
(*Earl of Rosse.*)

of the most striking of this class is 97 M [2343 H] Ursæ Majoris, R.A. $11^h\ 7^m\ 9^s$, Decl. $+55°\ 43{\cdot}2'$, close to the star β of that constellation, that is to say, $2°$ *sf.* It was discovered by Méchain in

(*Sir J. Herschel.*) (*Earl of Rosse.*)

THE SPIRAL NEBULA 57 ♅ I LEONIS.

THE SPIRAL NEBULA 99 M VIRGINIS.

(*Earl of Rosse.*)

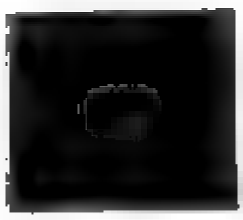
(*Sir J. Herschel.*) (*Earl of Rosse.*)

THE SPIRAL NEBULA 55 ♅ I PEGASI.

SPIRAL NEBULÆ.

1781, and is described as "a very singular object, circular and uniform, and after a long inspection looks like a condensed mass of attenuated light." Sir J. Herschel gave it a diameter of 2′ 40″.

Fig. 185.



(*Sir J Herschel.*)

Fig. 186.

(*Earl of Rosse.*)

PLANETARY NEBULA, 97 M URSÆ MAJORIS.

The late Earl of Rosse detected perforations and a spiral tendency in it. To Huggins it yields a gaseous spectrum. Other planetary nebulæ will be found as follows:—

No.	Name.	H.'s Cat. of 1864.	R.A. 1870.			Decl. 1870.	
			h.	m.	s.	°	′
1	26 ♅ IV Eridani .. .	826	4	8	18	− 13	4·4
2	1565 H Argûs	1565	7	35	52	− 14	31·3
3	1843 H Argûs (Car.) ..	1843	9	17	[illegible]	− 57	45·8
4	27 ♅ IV Hydræ .. .	2102	10	18	31	− 17	58.8
5	2581 H Centauri	2581	11	43	53	− 56	27·3
6	3614 H Virginis	3614	13	31	2	− 17	13·1
7	4234 H Herculis	4234	16	39	1	+ 24	2·3
8	50 H IV Herculis ..	4244	16	43	23	+ 47	50·2
9	37 ♅ IV Draconis ..	4373	17	58	20	+ 66	38·0
10	743 ♅ III Aquilæ . ..	4487	19	12	7	+ 6	18.6
11	51 ♅ IV Sagittarii ..	4510	19	36	38	− 14	27·6
12	73 ♅ IV Cygni	4514	19	41	23	+ 50	11·8
13	1 ♅ IV Aquarii	4628	20	57	5	− 11	52·8
14	18 ♅ IV Andromedæ ..	4964	23	19	38	+ 41	49·4

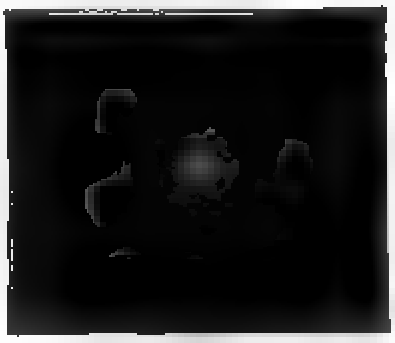
No. 1 is described by Lassell as the most interesting and extraordinary object which he had ever seen: an 11th-mag. star standing in the centre of a circular nebula, itself placed centrally upon a

larger and fainter circle of hazy light. To Huggins it yields a non-gaseous spectrum, though deficient at the red end.

No. 2 is a faint object near 46 M Argûs, which Lassell and the late Earl of Rosse found to be annular rather than strictly "planetary."

No. 4 was described by Smyth as resembling Jupiter. Secchi's large refractor at Rome entirely alters the features of this object as seen with less powerful instruments. Spectrum, gaseous.

Fig. 187.



PLANETARY NEBULA,
3614 H VIRGINIS.
R.A. $13^h\ 31^m\ 2^s$,
Decl. $-17°\ 13{\cdot}1'$.
(*Sir J. Herschel.*)

No. 9 is large and bright of its class, according to Webb, and "much like a considerable star out of focus." Spectrum, gaseous. So found in 1864 by Huggins, and the first of his discoveries in this field.

No. 11 has been found by Huggins to exhibit a gaseous spectrum.

No. 13 is a somewhat oval and fairly bright nebula. As in so many other like instances, the "planetary" features disappear in very large telescopes, and it yields a gaseous spectrum.

No. 14 is a small but bright object. Lassell noticed it to comprise a nucleus and 2 oval rings, out of which the late Earl of Rosse evolved a spiral structure. Huggins obtains a spectrum of 4 gaseous lines, the form of the nebula being annular.

Some peculiarities may be mentioned as connected with planetary nebulæ: three-fourths of those known are situated in the Southern hemisphere; they are mostly gaseous (if spectroscopy is to be relied on), and several are noticeably of a blue tinge.

Nebulous stars are so called because they are surrounded by a faint nebulosity, usually of a circular form, and sometimes several minutes in diameter. Hind remarks that the nebulosity is, in some cases, well defined, but in other cases quite the reverse. He also says that "the stars thus attended have nothing in their appearance to distinguish them from others entirely destitute of such appendages; nor does the nebulous matter in which they are situated offer the slightest indications of resolvability into stars with any telescopes hitherto constructed." The following stars are instances of this kind:—

No.	Name.	H's Cat. of 1864.	R. A. 1870.			Decl. 1870.	
			h.	m.	s.	°	′
1	ι Orionis	1183	5	29	3	− 5	59·8
2	θ Orionis	1193	5	29	37	− 1	17·2
3	45 ♅ IV Geminorum ..	1532	7	21	30	+ 21	10·4
4	8 Canum Venaticorum ..	3079	12	27	37	+ 42	4·3

No. 1 is a triple star, A 3½, B 8½, and C 11, dist. 11·5″ and 49″, the whole being involved in a large nebulous *ring* 3′ in diameter.

Fig. 188.

Nebulous Star, ι Orionis. (*Earl of Rosse.*)

No. 2 is a 2½-mag. star, "involved in an immense nebulous atmosphere."

No. 3 is an 8th-mag. star, which, according to Sir J. Herschel, lies "exactly in the centre of a round bright atmosphere 25″ in diameter." The Rev. H. C. Key[k], who has paid special attention to this object, describes it as "a bright but somewhat nebulous star closely surrounded by a dark ring; this again by a luminous ring;

Fig. 189.

Nebulous Star, 45 ♅ IV Geminorum. (*Rev. H. C. Key.*)

then an interval much less luminous, and, finally, at some distance

[k] *Month. Not.*, vol. xxviii. p. 154. March 1868.

an exterior luminous ring,"—a description which accords well with the late Earl of Rosse's, derived from his much more powerful telescope.

No. 4 is a $4\frac{1}{2}$-mag. star, "involved in a considerable nebula 3′ in diameter, exactly round."

Only with large telescopes can nebulous stars be scrutinised with any satisfactory results.

Besides the clusters and nebulæ belonging to the foregoing classes, there are others for the most part of irregular form and large dimensions, which it is convenient to class by themselves. Under this head may be included the following:—

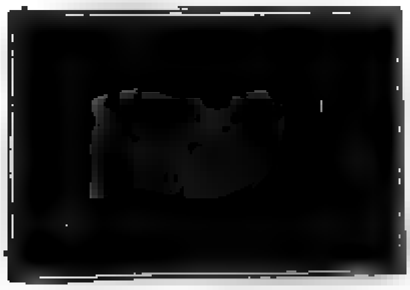
No.	Name.	H.'s Cat. of 1864.	R.A. 1870.			Decl. 1870.	
			h.	m.	s.	°	′
1	47 Toucani	52	0	18	14	− 72	48·2
2	1 M Tauri	1157	5	26	40	+ 21	55·3
3	42 M Orionis	1179	5	28	53	− 5	28·6
4	30 Doradûs	1269	5	39	36	− 69	10·0
5	η Argûs	2197	10	40	0	− 58	59·9
6	κ Crucis	3275	12	45	57	− 59	38·6
7	ω Centauri	3531	13	18	59	− 46	38·0
8	41 H IV Sagittarii	4355	17	54	28	− 23	2·0
9	8 M Sagittarii	4361	17	55	54	− 24	21·5
10	17 M Clypei Sobieskii ..	4403	18	13	8	− 16	13·4
11	27 M Vulpeculæ	4532	19	53	55	+ 22	21·9
12	4618 H Cygni	4618	20	51	44	+ 29	42·9

The remarks which follow in inverted commas are nearly all by Sir John Herschel, though an actual reference to that effect is not in every case given.

No. 1 (47 Toucani) was described by Sir J. Herschel as "a superb globular cluster, immediately preceding the *nubecula minor*; it is very visible to the naked eye, and one of the finest objects in the heavens. It consists of a very condensed spherical mass of stars, of a pale rose colour, concentrically enclosed in a much less condensed globe of white ones 15′ or 20′ in diameter." In his account of this cluster Sir John remarked that he could not remember a single elliptical nebula which is resolvable, all the resolvable

clusters being more or less circular in their outlines. "Between these 2 characters then (ellipticity of form and difficulty of resolution) there undoubtedly exists some physical connexion. . . . It deserves also to be noticed that in very elliptic nebulæ which have a spherical centre (as in 65 M), a resolvable or mottled

Fig. 190.



(*Sir J. Herschel.*)

Fig. 191.

(*Earl of Rosse.*)
The "Crab" Nebula in Taurus.

character often distinguishes the central portion, while the branches exhibit nothing of the kind[1]."

No. 2 is frequently called the "Crab Nebula in Taurus." It has an elliptic outline in most instruments, but in Lord Rosse's

[1] *Results of Ast. Obs.*, p. 19. An exception to this rule is 1 M Tauri.

reflector "it is transformed into a closely-crowded cluster, with branches, streaming off from the oval boundary, like claws, so as to give it an appearance that in a measure justifies the name

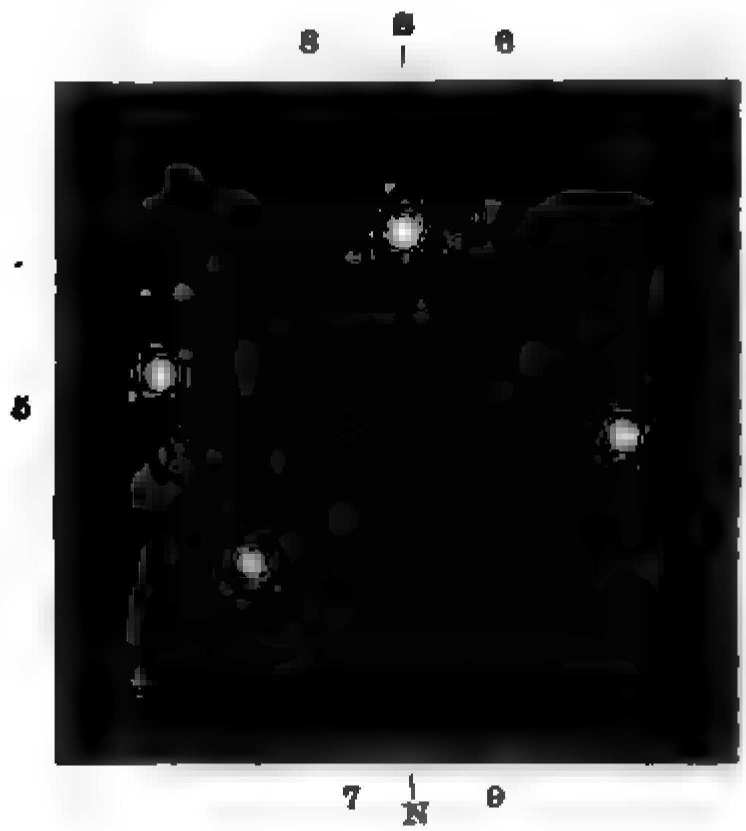
Fig. 192.

THE GREAT NEBULA IN ORION. (*Tempel*)

by which it is distinguished." It was the accidental discovery of this nebula in 1758, when he was following a comet, that led Messier to form his well-known Catalogue of Nebulæ, the first of its kind.

No. 3 is the "Great Nebula in the sword-handle of Orion," surrounding the multiple star θ in that constellation. It was discovered by Huyghens about the year 1656. "In its more prominent details may be traced some slight resemblance to the wing of a bird. In the brightest portion are 4 conspicuous stars forming a trapezium. The nebulosity in the immediate vicinity of these stars is flocculent, and of a greenish white tinge; about half a degree northward of the trapezium are 2 stars involved in a bright branching nebula of singular form, and southward is the

Fig. 193.



The Trapezium of Orion, January 1866. (*Huggins.*)

star ι Orionis, also situated in a nebula. Careful examination with powerful telescopes has traced out a continuity of nebulous light between the great nebula and both these objects, and there can be but little doubt that the nebulous region extends northwards as far as ϵ in the belt of Orion, which is involved in a strong nebulosity, as well as several smaller stars in the immediate neighbourhood." Secchi, in fact, says that the nebulous mass in Orion has, speaking roughly, a triangular outline with a base of about 4°, and a height of about $5\frac{1}{2}$°, reaching downwards from ζ, the apex (with a break, however, at σ), almost as far

as v[m]. The "Trapezium" of stars in this nebula deserves a few additional words on its own account. Four stars were long known. In 1826 W. Struve found a fifth, and four years later Sir J. Herschel a sixth. Since then other stars have been seen with more or less certainty, and Huggins puts up the total number to 9, as in the engraving on p. 532. Numerous observations[n] by different astronomers, at different dates, and with instruments of widely different size and character, are only explicable on the supposition that most

Fig. 194.

THE NEBULA 30 DORADUS. (*Sir J. Herschel.*)

of the smaller stars of the Trapezium are variable. The four brightest stars are respectively of mags. 6, 7, 7½, and 8. All the rest are much smaller.

No. 4 (30 Doradûs) is a singular nebula, faintly visible to the naked eye, situated within the limits of the *nubecula major;* it was noticed by La Caille as resembling the nucleus of a comet, and is one of the most singular and extraordinary objects in the heavens.

[m] See Struve, *Month. Not.*, vol. xvii. pp. 225–30, June 1857; W. C. Bond, *Mem. Amer. Acad.*, vol. iii. New Series, p. 87; Sir J. Herschel, *Results of Ast. Obs.*, pp. 25–32; *Outlines of Ast.*, p. 650; Secchi, *Month. Not.*, vol. xviii. p. 8, Nov. 1857; G. P. Bond, *ibid.*, vol. xxi. p. 203, May 1861; Liapounov, *ibid.*, vol. xxiii. p. 228, May 1863—for various remarks on this nebula.

[n] See for some of these Huggins's paper on the subject in *Month. Not.*, vol. xxvi. p. 71. Jan. 1866.

No. 5 is a very large nebula surrounding the star η Argûs, and occupying a space equal to about 5 times the area of the Moon. Sir J. Herschel, who carefully examined this object when he was at the Cape of Good Hope in 1833 and following years, said that "viewed with an 18-inch reflector no part of this strange object shews any sign of resolution into stars, nor in the brightest and most condensed portion, adjacent to the singular oval vacancy in the middle of the figure, is there any of that curdled appearance, or that tendency to break up into bright knots with intervening

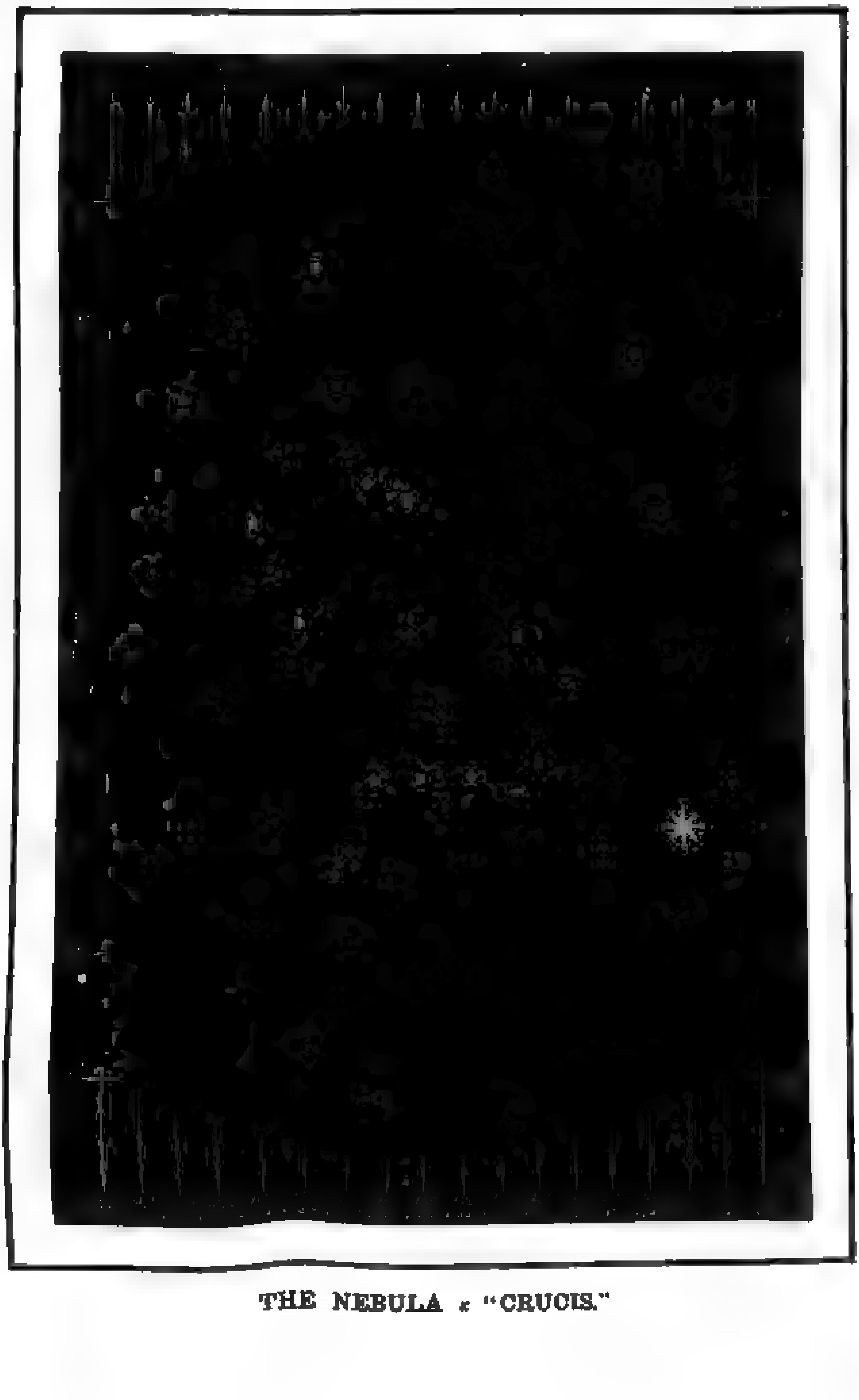
Fig 195.

The Nebula surrounding η Argûs. (*Sir J. Herschel.*)

darker portions, which characterise the nebula of Orion, and indicate its resolvability. . . . . It is not easy for language to convey a full impression of the beauty and sublimity of the spectacle which this nebula offers, as it enters the field of the telescope (fixed in R.A.) by the diurnal motion, ushered in as it is by so glorious and innumerable a procession of stars, to which it forms a sort of climax*." Some recent observations on a point of great importance concerning this nebula will be alluded to hereafter.

* Sir J. Herschel, *Outlines of Ast.*, p. 652; see also *Results of Ast. Obs.*, pp. 32–47.

Fig. 196. *Plate* XXVI.



THE NEBULA κ "CRUCIS."

No. 6. The nebula surrounding κ Crucis was described by Sir J. Herschel as one of the most beautiful objects of its class: it consists of about 110 stars from the 7th magnitude downwards, 8 of the more conspicuous of them being coloured various shades of red, green, and blue. The accompanying plate is the result of observations made by Mr. W. C. Russell at Sydney, N. S. W., in March and April 1872. The lines on the edges of the engraving represents scales of distance reckoned from the principal star. Mr. Russell remarks that "many of the stars have drifted" since the drawing by Sir J. Herschel was made, and he has seen 25 stars not noted by Herschel, although using a smaller telescope than the Cape one. "The colours of this cluster are very beautiful, and fully justify Herschel's remark that it looks like a 'superb piece of fancy jewellery[p].'"

No. 7 (ω Centauri) is visible to the naked eye, and resembles a tail-less comet: its brilliancy is about equal to that of a $4\frac{1}{2}$-magnitude star, but, "viewed in a powerful telescope, it appears as a globe of fully 20′ in diameter, very gradually increasing in brightness to the centre, and composed of innumerable stars of the 13th and 15th magnitudes[q]."

No. 8 (41 H IV Sagittarii) is the chief member of an important group of nebulæ. "One of them [1991 h] is singularly trifid, consisting of 3 bright and irregularly formed nebulous masses, graduating away insensibly externally, but coming up to a great intensity of light at their interior edges, where they enclose and surround a sort of three-forked rift or vacant area, abruptly and uncouthly crooked, and quite void of nebulous light. A beautiful triple star is situated precisely on the edge of one of these nebulous masses, just where the interior vacancy forks out into two channels[r]."

No. 9 (8 M Sagittarii). "A collection of nebulous folds and masses, surrounding and including a number of oval dark vacancies, and in one place coming up to so great a degree of brightness as to offer the appearance of an elongated nucleus. Superposed upon this nebula, and extending in one direction beyond its area, is a fine and rich cluster of scattered stars, which seem to have no connexion with it, as the nebula does not, as in the region of Orion, shew any

[p] *Month. Not.*, vol. xxxiii. p. 66, Dec. 1872.

[q] Sir J. Herschel, *Outlines of Ast.*, p. 637; see also *Results of Ast. Obs.*, p. 21.

[r] Sir J. Herschel, *Outlines of Ast.*, p. 653.

tendency to congregate about the stars." Webb describes this object as a "splendid galaxy cluster visible to the naked eye."

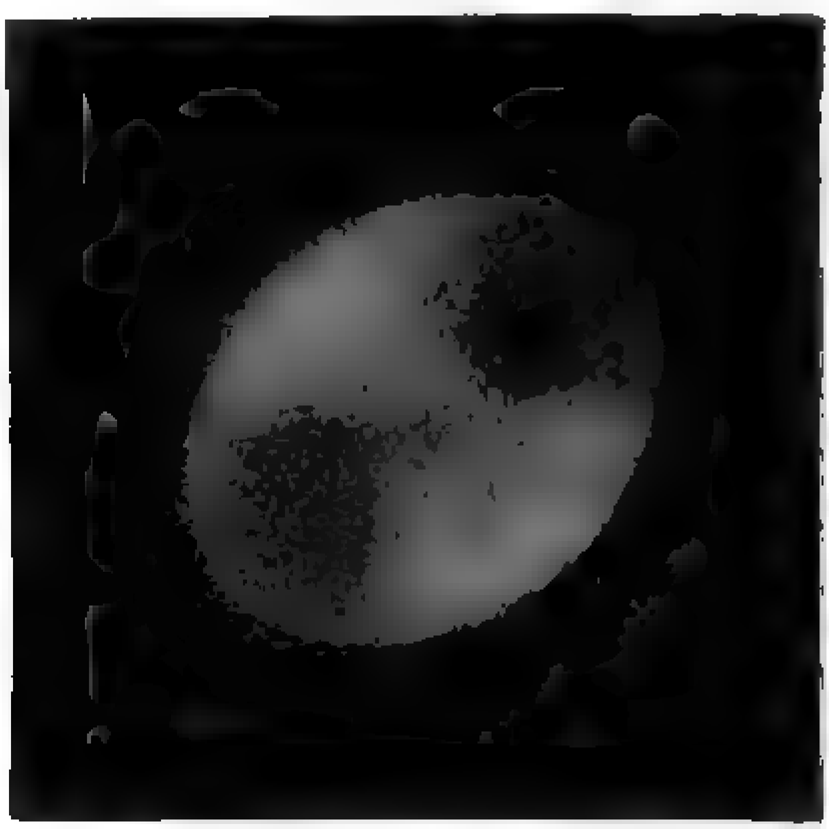
No. 10 is frequently but not very judiciously termed the "Horse-shoe nebula" from a certain peculiarity in its form: this name, however, can only be applied to the most prominent portion, for there is an important outlier; and when this is seen, and also the bright lens-like band which unites it with the principal mass, the whole object resembles a pair of capital Greek omegas connected at their bases. In ordinary telescopes the outline resembles that of a swan minus its legs! Huggins finds it to be gaseous.

Fig. 197.

The Nebula 17 M Clypei Sobieskii. (*Chambers.*)

No. 11 is a curious object near the 5th-magnitude star 14 Vulpeculæ; it is shaped like a double-headed shot, or dumb-bell, and

Fig. 198.



The "Dumb-bell" Nebula in Vulpecula. (*Sir J. Herschel.*)

is usually known as the "Dumb-bell" nebula. In a small telescope

it appears like two roundish nebulosities, in contact the one with the other, or nearly so. Sir J. Herschel saw it with "an elliptical outline of faint light enclosing the two chief masses," but Lord Rosse's reflectors materially change the appearance of the object:

Fig. 199.

THE "DUMB-BELL" NEBULA IN VULPECULA.
(*Earl of Rosse*: 3-ft. Reflector.)

his 3-ft. reflector destroys the regular elliptic outline seen by Sir J. Herschel, and his 6-ft. instrument makes the general outline to resemble that of a chemical retort and reveals many stars.

The history of the successive stages in the observation of this nebula affords a striking illustration of the fallacy associated with the exploded "Nebular hypothesis."

Fig. 200.

THE "DUMB-BELL" NEBULA IN VULPECULA.
(*Earl of Rosse*: 6-ft. Reflector.)

No. 12 (4618 H Cygni). "A most wonderful phenomenon. A very large space, 20′ or 30′ broad in P. D. and 1^m or 2^m in R. A., full of nebula and stars mixed. The nebula is decidedly attached to the stars, *and is as decidedly not stellar.* It forms irregular lacework marked out by stars, but some parts are decidedly nebulous, wherein no stars can be seen."

In the southern hemisphere, and not far from the Pole, are the Magellanic clouds, or *Nubeculæ Major* and *Minor*, so called from their cloud-like appearance. The former is situated in the constellation Dorado, and the latter in Toucan. They are of a somewhat oval shape, and are both visible to the naked eye when the Moon is not shining; but the smaller disappears in strong moon-light. Sir J. Herschel, when at the Cape, examined these remarkable objects with his large telescope, and described them as consisting of swarms of stars, clusters, and nebulæ of every description. The larger one covers an area of about 42 square degrees, and the smaller of 10 square degrees.

The nebulæ are very far from being uniformly distributed in

the heavens, but congregate especially in a zone crossing at right angles the Milky Way. They are exceedingly abundant in the constellation Virgo. Sir J. Herschel's Catalogue of 1864 contains 5079 of these objects, which are thus distributed through the different hours of R.A. :—

0 Hour	211 Neb.	XII Hour.. ..	686 Neb.
I „	278 „	XIII „	252 „
II „	161 „	XIV „	263 „
III „	163 „	XV „	114 „
IV „	198 „	XVI „	109 „
V „	352 „	XVII „	108 „
VI „	139 „	XVIII „	92 „
VII „	132 „	XIX „	79 „
VIII „	135 „	XX „	90 „
IX „	252 „	XXI „	120 „
X „	294 „	XXII „	142 „
XI „	421 „	XXIII „	163 „

On the distribution of the nebulæ[a], Guillemin remarks as follows :—

"This is very unequal in the Northern hemisphere, and in those parts of the Southern one visible in the Northern temperate zone. The greatest number is found in a zone which scarcely embraces the eighth part of the heavens. The constellations Leo, Ursa Major, Camelopardus, Draco, Boötes, Coma Berenices, and Canes Venatici, but principally Virgo, form this zone, which extends as far as the middle of Centaurus: it is known under the name of the nebulous region of Virgo. Nearly at the opposite pole of the sky, another agglomeration of nebulæ embraces Andromeda, Pegasus, and Pisces, and extends lower than the first-named constellation into the Southern heavens.

"It is noteworthy that the regions nearest the Milky Way are the poorest in nebulæ, whilst the two richest regions lie at the two poles of that great belt in which the stars are so numerous and condensed. The nebulæ are more uniformly spread over the zone which surrounds the South Pole; they are at the same time much less numerous. On the other hand, there are two

[a] Readers interested in this matter should study an elaborate paper by C. Abbe in *Month. Not.*, vol. xxvii. p. 257 (May 1867), followed by others by R. A. Proctor in *Month. Not.*, vol. xxix. p. 357 (Oct. 1869); and by S. Waters in *Month. Not.*, vol. xxxiii. p. 558 (Oct. 1873).

magnificent regions there, which alone contain nearly 400 nebulæ and star-clusters[t]."

In connection with the distribution of the nebulæ it may here be mentioned that almost all the nebulæ indicated by the spectroscope to be gaseous are situated either within or on the borders of the Milky Way, whilst in the regions near the poles of the Milky Way such nebulæ are wanting, though of other nebulæ there are no lack there. These facts may hereafter prove to be of great significance.

The first who paid much attention to clusters and nebulæ was the French astronomer Messier, who formed the well-known and important, though small Catalogue, the constituents of which are still distinguished by his initial—M. After him came Sir W. Herschel, who classified the nebulæ which he observed in the following way:—

I. "Bright nebulæ."
II. "Faint nebulæ."
III. "Very faint nebulæ."
IV. "Planetary nebulæ, stars with bars, milky chevelures, short rays remarkable shapes," &c.
V. "Very large nebulæ."
VI. "Very compressed rich clusters."
VII. "Pretty much compressed clusters."
VIII. "Coarsely scattered clusters."

Objects catalogued by this observer are usually indicated by the symbol ℍ, with the number of the class in Roman capitals; thus—33 ℍ VI Persei. References to Sir John Herschel's Catalogue of 1833, and his Cape extension of it, are indicated by the letter h with the number prefixed. For the great Catalogue of 1864 (the publication of which marks an era in this branch of the science) no designating letter has yet been agreed upon, but perhaps the capital H would be as convenient as any that could be chosen.

The other observers who must be cited as having devoted much attention to nebulæ and clusters are the late Earl of Rosse in England, and MM. D'Arrest, Schönfeld, and Schultz on the Continent. The late Earl of Rosse laid before the Royal Society,

[t] *The Heavens*, Eng. ed., p. 395.

in 1861, a large and valuable Catalogue of 989 nebulæ observed by himself at Parsonstown, which appeared in vol. cli. of the *Philosophical Transactions*. Some further information respecting the work done of late years in this branch of sidereal astronomy may be gleaned from the list of Catalogues (*post*).

The following abbreviations relate to words which were made special use of by Sir J. Herschel in his Catalogues of Nebulæ, and as they have been adopted by various observers writing in various languages, a statement of Sir John's terminology will frequently be found useful[u] :—

ab	about.
alm	almost.
am	among.
app	appended.
att	attached.
B	bright.
b	brighter.
bet	between.
biN	bi-nuclear.
bn	brightest towards the North side.
bs	brightest towards the South side.
bp	brightest towards the preceding side.
bf	brightest towards the following side.
C	compressed.
c	considerably.
co	coarse, coarsely.
com	cometic.
cont	in contact.
cl	cluster.
D	double.
d	diameter.
diffic	difficult.
dif	diffused.
dist	distance, distant.
def	defined.
E	extended.
e	extremely.
ee	excessively.
er	easily resolveable.
exc	excentric.
F	faint.
f	following.
g	gradually.
gr	group.
inv	involved.
i	irregular.
iF	irregular Figure.
L	large.
l	long, or little.
M	in the middle.
m	much.
mm	mixed magnitudes.
mn	milky nebulosity.
N	nucleus, or to a nucleus.
neb	nebula.
nr	near.
n	North.
np	north preceding.
nf	north following.
P	poor.
p	pretty (before F, B, L, S, &c.); otherwise, it means preceding.
pg	pretty gradually.
pm	pretty much.
ps	pretty suddenly.
pos	angle of position.
R	round.
RR	exactly round.
Ri	rich.

[u] This table has been taken from his *General Catalogue*, p. 11, but I have excluded a few words which are of limited applicability, and I have varied the order a little in some cases.

r	resolvable, barely (mottled as if with stars).
rr	partially resolved—some stars visible.
rrr	well resolved—clearly seen to consist of stars.
S	small.
sm	smaller.
s	south, suddenly.
sp	south preceding.
sf	south following.
st	stars.
sc	scattered.
sev	several.
susp	suspected.
sh	shaped.
stell	stellar.
sw	sweep.
tri-N	tri-nuclear.
trap	trapezium.
v	very.
vv	very exceedingly.

☾	moon above the horizon.
☾☾	moon very bright.
*	star.
*10	a star of the 10^{th} magnitude.
$*_*$	double star.
$_*{}^*{}_*$	triple star.
!	a remarkable object.
!!	very much so.
!!!	a magnificent or otherwise exceedingly interesting object.
?	doubtful.
??	very doubtful either as to accuracy of place or reality of existence.
△	Dunlop; *or* forms a triangle with.
⊕	globular cluster.
O	planetary nebula.
⊙	annular nebula.
st. 9...	stars from the 9^{th} (or other) magnitude downwards.
st. 9...13	stars from the 9^{th} down to the 13^{th} magnitude.

CHAPTER V.

VARIABLE NEBULÆ.

Variable Nebula in Taurus.—Observations by Hind.—Variable Nebula in Scorpio.—Observations by Pogson and others.—Notes of observations on the other Nebulæ suspected to be variable.

CURIOUS and interesting as are those stars which undergo periodical changes of brilliancy, it seems probable that we shall have henceforth to consider it certain that there are variations in the light of nebulæ more or less analogous in character to those already recognised in the case of numerous single stars.

The following is a summary of a communication by Hind. On Oct. 11, 1852, that observer discovered, at the Regent's Park Observatory, a small nebula about 1′ in diameter, with a central condensation of light. Its position (reduced to 1860) was R.A. 4^h 13^m 47^s, and Decl. + 19° 11·2′, and therefore it was in the constellation Taurus, about 1½° distant from ϵ.

From 1852 to 1856 a star of the 10th magnitude almost touched the *nf* edge of the nebula; this star was first noticed on the night of the discovery of the nebula, and from the fact that it had escaped observation on many previous occasions when the same locality had been under examination, Hind was induced to suspect its variability—a suspicion which eventually was shewn to be well-founded, as the star has now dwindled down to the 12th mag. But the most singular thing remains to be told: namely, that on Oct. 3, 1861, D'Arrest, of Copenhagen, found that the *nebula* had *totally vanished*. This statement was not

credited at the time on account of its apparent improbability, notwithstanding the known reputation of the observer who made it; and it was assumed, too hastily, that some error of observation had crept in, though D'Arrest's good faith was not at all questioned.

On Jan. 26, 1862, Le Verrier turned the large equatorial of the Paris Observatory (of 12·4 inches aperture) on the place of the nebula; not a single trace, however, could be obtained of it either by Le Verrier or by his assistant, Chacornac, and on the following night Secchi, at Rome, was similarly unsuccessful; thus was confirmed beyond a doubt the statement of D'Arrest. Chacornac, whilst engaged in 1854 in forming a chart of the stars in the neighbourhood of the nebula, saw it, but in going over the locality again in 1858, with a much more powerful instrument, he did not see it, though the reason why he did not announce the disappearance is not stated.

Hence Hind infers that the disappearance of the nebula took place either during 1856 or some time in the course of the following year. He further remarks: "How the variability of a nebula and a star closely adjacent is to be explained, it is not easy to say in the actual state of our knowledge of the constitution of the sidereal universe. A dense but invisible body of immense extent interposing between the Earth and them might produce effects which would accord with those observed; yet it appears more natural to conclude that there is some intimate connexion between the star and the nebula upon which alternations of visibility and invisibility of the latter may depend. If it be allowable to suppose that a nebula can shine by light reflected from a star, then the waning of the latter might account for the apparent extinction of the former; but in this case it is hardly possible to conceive that the nebula can have a stellar constitution[a]."

On Dec. 29, 1861, the nebula was again seen in the 15-inch refractor at Pulkova, and by March 22, 1862, it had so far increased in brightness as to bear a faint illumination. But on Dec. 12, 1863, Hind and Talmage carefully looked for it with the telescope with which it was originally observed, and failed

[a] Letter in the *Times*, Feb. 4, 1862. See a further communication in *Month. Not.*, vol. xxiv. p. 65, Jan. 1864, and D'Arrest's paper in *Ast. Nach.*, vol. lvii. No. 1366, June 26, 1862.

to establish any trace of its visibility. The telescope in question (Mr. Bishop's) has only half the aperture of the one at Pulkova.

It is satisfactory to know that the preceding instance does not altogether stand alone, but that something at least analogous is on record. In the autumn of 1860 Mr. N. Pogson, then assistant at the Hartwell Observatory, and now Director of the Madras Observatory, communicated to the Royal Astronomical Society a paper, of which the following is the substance.

The 80th object in Messier's Catalogue of Nebulæ, although described as a compressed cluster, had always presented to Pogson the appearance of a well-defined *nebula*, and as it was in the same field of view with R and S Scorpii, had frequently come under his notice. On May 28, 1860, when seeking for these two variables, neither of which was then visible, his attention was arrested by the startling fact, that a star of about the 7th mag. was in the place previously occupied by the nebula. The power used was 118 on the Hartwell equatorial; and so recently as May 9 (the last night on which R Scorpii was visible) Pogson saw the nebula, and is positive that it appeared exactly the same as usual, without anything stellar about it, the self-same instrument and power being employed. On June 10, with a power of 66, the stellar appearance had nearly vanished, but the cluster still shone with unusual brilliancy, and with a marked central condensation. Pogson's remarkable observations were fully confirmed by the independent testimony of E. Luther and Auwers[b].

Pogson concludes with the following remarks: "It is therefore incontestably proved, upon the evidence of three witnesses, that between May 9 and June 10 [1860] the cluster known as 80 Messier changed apparently from a pale cometary-looking object to a well-defined star, fully of the 7th magnitude, and then returned to its usual and original appearance. It seems to me absurd to attribute this phenomenon to actual change in the cluster itself, but it is very strange if a new variable star, the third in the same field of view, should be situated between us and the centre of the cluster. Should such be the true explanation, the midway variable star must be similar in nature, but of greater range, than Mr. Hind's wonderful U Geminorum. The cluster should be closely watched[c]."

[b] *Ast. Nach.*, vol. liii. No. 1267. July 1860.

[c] *Month. Not.*, vol. xxi. p. 32. Nov. 1860.

On Sept. 1, 1859, H. P. Tuttle discovered a nebula in Draco (4415 H, R.A. $18^h\ 23^m\ 18^s$, Decl. $+74°\ 30{\cdot}5'$), which D'Arrest and others stated to be so bright as to make it inexplicable how it should have escaped the notice of Sir W. and Sir J. Herschel, if it had always been of uniform brilliancy.

On Oct. 19, 1859, Tempel observed in Taurus an object which he took to be a new telescopic comet. The next evening, however, finding it still in the same position, he was able to determine that it was not a comet, but a nebula. On Dec. 31, 1860, it was seen again by Tempel and Pape, though with some difficulty. Auwers, who has also seen it, describes it as triangular in form, and 15′ in extent, but he thinks that it might have escaped notice owing to its proximity to a bright star—Merope, one of the Pleiades. Schiaparelli, at Milan, trying a new telescope on Feb. 25, 1875, saw this nebula very clearly, and was much surprised at its size. He noted it to extend from the star Merope, beyond Electra and as far as Celæno[d]. It may be added that Hind states that he has often suspected nebulosity about some of the smaller outlying stars of the Pleiades. The position of this nebula (which is 768 H) is R.A. $3^h\ 38^m\ 28^s$, and Decl. $+23°\ 21{\cdot}7'$.

On October 19, 1855, Chacornac discovered a nebula also in Taurus, which had not been previously observed. This object, which is 1191 H, R.A. $5^h\ 29^m\ 40^s$, Decl. $+21°\ 8{\cdot}1'$, was so conspicuous that he felt some difficulty in understanding how it could have escaped earlier notice if it had always possessed the same brilliancy[e].

The foregoing observations may be said to have relation to objects of small size, but there are some slight grounds for the opinion that there is one example of an important nebula undergoing changes of form. The great nebula in Argo, when observed by Sir J. Herschel in 1838, contained within its area a vacuity of considerable size. The star η, then of the 1st magnitude, was situated in the most dense part of the nebula, and was completely encompassed by nebulous matter. In 1863, according to Abbott of Hobart-Town, the star, which had dwindled down to the 6th magnitude (a matter already alluded to[f]), *was entirely free from*

[d] *Ast. Nach.*, vol. lxxxvi. No. 2045, July 10, 1875. A translation appears in *Ast. Reg.*, vol. xiii. p. 194, Aug. 1875.

[e] *Bulletin Météorologique*, April 28, 1863.

[f] See p. 500, *ante*.

nebulosity. This observer also states[g] that the outline of the vacuity is materially different from the representation given by Herschel. Mr. E. B. Powell, of Madras, confirmed these remarks generally, but also stated that the nebula as a whole has varied much in brilliancy during the time it had been under his notice[h].

Consequent on the publication of Abbott's several communications, Capt. J. Herschel in India and Dr. Gould at Corduba in South America directed their attention to this nebula in 1868 and following years. Capt. Herschel's own observations were compared by himself[i], by Sir J. Herschel[k], by Sir G. B. Airy[l], and Mr. Lassell with Sir John Herschel's observations at the Cape in 1834, &c., and with Abbott's comments thereon, and the general opinion of astronomers may be gathered from the Report of the Council of the Royal Astronomical Society of 1872, where Dr. Gould's words are quoted with evident approval[m]. That observer had stated that he was strongly impressed "with the conviction that the alleged change is altogether imaginary," and astronomers are now agreed to pass an unfavourable opinion on Mr. Abbott's assertions[n].

[g] *Month. Not.*, vol. xxi. p. 230, June 1861; vol. xxiv. p. 5, Nov. 1863; vol. xxv. p. 192, April 1865; vol. xxviii. p. 200, May 1868; and vol. xxxi. p. 226, June 1871. Sir J. Herschel's earliest comment on Abbott's statements will be found in vol. xxviii. p. 225, June 1868.

[h] *Month. Not.*, vol. xxiv. p. 171, May 1864.

[i] *Month. Not.*, vol. xxix. p. 82, Jan. 1869.

[k] *Month. Not.*, vol. xxix. p. 84, Jan. 1869; vol. xxxi. p. 228, June 1871.

[l] *Month. Not.*, vol. xxxi. p. 233, June 1871.

[m] *Month. Not.*, vol. xxxii. p. 178, Feb. 1872.

[n] See, for instance, a memorandum by Proctor in *Month. Not.*, vol. xxxii. p. 62, Dec. 1871.

CHAPTER VI.

THE MILKY WAY.

Its course amongst the stars described by Sir J. Herschel.—The "Coal Sack" in the Southern Hemisphere.—Remarks by Sir W. Herschel as to the prodigious number of stars in the Milky Way.—Computation by Sir J. Herschel of the total number of stars visible in an 18-inch reflector.—Terms applied to the Milky Way by the Greeks.—By the Romans.—By our ancestors.

FOREMOST amongst the great clusters with which we are acquainted stands the Milky Way, which has pre-eminently occupied the attention of philosophers from the earliest ages of antiquity.

The course of the Milky Way amongst the constellations is well sketched by Sir J. Herschel, whose description I shall use, with a few verbal alterations[a].

Neglecting occasional deviations, and following the line of its greatest brightness as well as its varying breadth and intensity will permit, its course conforms nearly to that of a great circle inclined at an angle of about 63° to the equinoctial, and cutting that circle in R.A. 0^h 47^m, and 12^h 47^m; so that its Northern and Southern poles respectively are situated in R.A. 12^h 47^m, Decl. N. 27° and R.A. 0^h 47^m, Decl. S. 27°. Throughout the region where it is so remarkably subdivided this great circle holds an intermediate situation between the two great streams; with a nearer approximation, however, to the brighter and continuous stream than to the fainter and interrupted one. If we trace its course in order of Right Ascension, we find it traversing the constellation Cassiopeia, its brighter part passing about 2° North of the star δ of that constellation, *i.e.* in about 62° of North declination.

[a] *Outlines of Ast.*, p. 569.

Passing thence between γ and ϵ Cassiopeiæ, it sends off a branch to the south-preceding side, towards α Persei, very conspicuous as far as that star, prolonged faintly towards ϵ of the same constellation, and possibly traceable towards the Hyades and Pleiades as remote outliers. The main stream, however (which is here very faint), passes on through Auriga, over the three remarkable stars ϵ, ζ, η of that constellation preceding Capella (α Aurigæ), and called the Hædi, between the feet of Gemini and the horns of the Bull (where it intersects the ecliptic, nearly in the solstitial colure), and thence over the club of Orion to the neck of Monoceros, intersecting the equinoctial in R.A. 6^h 54^m. Up to this point, from the offset in Perseus, its light is feeble and indefinite, but thenceforward it receives a gradual accession of brightness, and when it passes through the shoulder of Monoceros, and over the head of Canis Major, it presents a broad, moderately bright, very uniform, and, to the naked eye, slender stream up to the point where it enters the prow of the ship Argo, nearly in the Southern Tropic. Here it again subdivides (about the star *m* Puppis), sending off a narrow and winding branch on the preceding side as far as γ Argûs, where it terminates abruptly. The main stream pursues its southward course to the 33rd parallel of South Declination, where it diffuses itself broadly and again subdivides, opening out into a wide fan-like expanse, nearly 20° in breadth, formed of interlacing branches, all of which terminate abruptly, in a line drawn nearly through λ and γ Argûs.

At this place the continuity of the Milky Way is interrupted by a wide gap, and when it recommences on the opposite side it is by a somewhat similar fan-shaped assemblage of branches which converge upon the bright star η Argûs. Thence it crosses the hind feet of the Centaur, forming a curious and sharply-defined semi-circular concavity of small radius, and enters the Cross by a very bright neck or isthmus not more than 3° or 4° in breadth—this is the narrowest portion of the Milky Way. After this it immediately expands into a broad and bright mass, enclosing the stars α and β Crucis, and β Centauri, and extending almost up to α of the latter constellation. In the midst of this bright mass, surrounded by it on all sides, and occupying about half its breadth, occurs a singular dark pear-shaped vacancy, so conspicuous and remarkable as to attract the notice of the most superficial gazer,

and to have acquired, amongst the early southern navigators, the uncouth but expressive appellation of the "Coal Sack." In this vacancy, which is about 8° in length and 5° in breadth, only one very small star visible to the naked eye occurs, though it is far from devoid of telescopic stars, so that its striking blackness is simply due to the effect of contrast with the brilliant ground with which it is on all sides surrounded. This is the place of the nearest approach of the Milky Way to the South Pole. Throughout all this region its brightness is very striking, and when compared with that of its more Northern course, already traced, conveys strongly the impression of greater proximity, and would almost lead to a belief that our situation as spectators is separated on all sides by a considerable interval from the dense body of stars composing the Galaxy, which in this view of the subject would come to be considered as a flat ring of immense and irregular breadth and thickness, within which we are eccentrically situated, nearer to the Southern than to the Northern part of its circuit.

At α Centauri the Milky Way again subdivides, sending off a great branch of nearly half its breadth, but which thins off rapidly at an angle of about 20° with its general direction towards the preceding side to η and d Lupi, beyond which it loses itself in a narrow and faint streamlet. The main stream passes on, increasing in breadth to γ Normæ, where it makes an abrupt elbow, and again subdivides into one principal and continuous stream of very irregular breadth and brightness on the following side, and a complicated system of interlaced streaks and masses on the preceding, which covers the tail of Scorpio, and terminates in a vast and faint effusion over the whole extensive region occupied by the preceding leg of Ophiuchus, extending Northwards to a parallel of 13° of South Declination, beyond which it cannot be traced, a wide interval of 14°, free from all appearance of nebulous light, separating it from the great branch on the North side of the equinoctial, of which it is usually represented as a continuation.

Returning to the point of separation of this great branch from the main stream, let us now pursue the course of the latter. Making an abrupt bend to the following side, it passes over the stars ι Aræ, θ and ι Scorpii, and γ Tubi to γ Sagittarii, when it

suddenly collects into a vivid oval mass about 6° in length and 4° in breadth, so excessively rich in stars that a very moderate calculation makes their number exceed 100,000. Northward of this mass this stream crosses the ecliptic in longitude about 276°, and proceeding along the bow of Sagittarius into Antinoüs, has its course rippled by three deep concavities, separated from each other by remarkable protuberances, of which the larger and brighter (situated between Flamsteed's stars 3 and 6 Aquilæ) forms the most conspicuous patch in the southern portion of the Milky Way visible in our latitudes.

Crossing the equinoctial at the 19th hour of Right Ascension, it next runs in an irregular, patchy, and winding stream through Aquila, Sagitta, and Vulpecula, up to Cygnus; at ϵ of which constellation its continuity is interrupted, and a very confused and irregular region commences, marked by a broad dark vacuity, not unlike the southern "Coal Sack," occupying the space between ϵ, α, and γ Cygni, which serves as a kind of centre for the divergence of three great streams: one which I have already traced; a 2nd, the continuation of the 1st (across the interval) from α Cygni Northward, between Lacerta and the head of Cepheus to the point in Cassiopeia whence we set out; and a 3rd branching off from γ Cygni, very vivid and conspicuous, running off in a Southern direction through β Cygni and s Aquilæ, almost to the equinoctial, when it loses itself in a region thinly sprinkled with stars, where in some maps the modern constellation Taurus Poniatowskii is placed. This is the branch which, if continued across the equinoctial, might be supposed to unite with the great Southern effusion in Ophiuchus, already noticed. A considerable offset, or protuberant appendage, is also thrown off by the Northern stream from the head of Cepheus directly towards the Pole, occupying the greater part of the quartile formed by α, β, ι, and δ of that constellation.

It is impossible to give any idea of the enormous number of stars in the Milky Way, but Sir W. Herschel recorded some facts that will assist us. That observer stated that on one occasion he estimated that 116,000 stars passed through the field of his telescope in ¼ hour[b]; and again that on Aug. 22, 1792, he saw 258,000 stars pass in 41m.[c] The surprising character of this result

[b] *Phil. Trans.*, vol. lxxv. p. 244. 1785. [c] *Ibid.*, vol. lxxxv. p. 70. 1795.

will be more adequately appreciated when compared with the number of stars that are visible to the naked eye. The common estimation gives between 3000 and 4000, though Struve augments the number to 6000 for persons of very acute vision[d].

Sir John Herschel computed that the total number of stars visible in an 18-inch reflector cannot be less than 5½ millions, and may probably be many more[e]. Struve's estimate for Sir W. Herschel's 20-ft. reflector is 20½ millions.

A brief reference must here be made to what is commonly known as Sir W. Herschel's theory of the Milky Way. He conjectured that the stars were not indifferently scattered through the heavens, but were rather arranged in a certain definite stratum, the thickness of which, as compared with its length and breadth,

Fig. 201.

Herschel's Stratum Theory.

was inconsiderable; and that the Sun occupies a place somewhere about the middle of its thickness, and near the point where it subdivides into 2 principal streams, inclined to each other at a small angle. It is clear, then, that to an eye viewing the stratum from S, the apparent density of the stars would be least in the direction S A, or S E, and greatest in the direction S B, S C, S D, and this corresponds generally to the observed facts[f]. "Such is the view of the construction of the starry firmament taken by Sir William Herschel[g], whose powerful telescopes first effected a

[d] *Études d'Astronomie Stellaire*, p. 61.

[e] *Results of Astron. Obs. &c.*, p. 381. For more on this subject, see *Outlines of Ast.*

[f] Hind, in *Atlas of Astronomy.*

[g] Thomas Wright, of Durham (see his *Theory of the Universe*, London, 1751), first started this idea in 1734. An analysis by Prof. De Morgan of this curious work will be found in the *Phil. Mag.*, 3rd ser., vol. xxxii. p. 241. April 1848.

complete analysis of this wonderful zone, and demonstrated the fact of its consisting entirely of stars[h]."

By the Greeks the Milky Way was termed the Γαλαξίας or Κύκλος γαλακτικός, and by the Romans the *Circulus lacteus* or *Orbis lacteus*; from our ancestors it received the names of *Jacob's Ladder*, *the Way to St. James's*, *Watling Street*, &c. The diversity of the ancient names was equalled only by the diversity of opinions that prevailed as to what it was. Metrodorus considered it to be the original course of the Sun, but that it was abandoned by him after the bloody banquet of Thyestes; others, that it pointed out the place of Phaëthon's accident; whilst a 3rd class thought that it was caused by the ears of corn dropped by Isis in her flight from Typhon. Aristotle imagined it to be the result of gaseous exhalations from the Earth, which were set on fire in the sky. Theophrastus declared it to be the soldering together of two hemispheres; and finally, Diodorus conceived it to be a dense celestial fire, shewing itself through the clefts of the starting and dividing semi-globes.

The speculations of Democritus[i] and Pythagoras were to the effect that the Galaxy was nothing more or less than a vast assemblage of stars. Ovid speaks of it as a high road "whose groundwork is of stars." Manilius uses similar language. In an English version of Manilius[k] his allusion to the Milky Way runs as follows:—

> "Or is the spacious bend serenely bright
> From little stars, which there their beams unite,
> And make one solid and conti..ued light?"

It is singular that Ptolemy has in none of his writings expressed any opinion on it. Our own ancestors supported the star theory.

In Milton we find mention of that—

> "broad and ample road,
> Whose dust is gold, and pavement, stars."

[h] This paragraph is in substance taken from Sir John Herschel's *Outlines of Ast*, p. 569, a source of information selected for the obvious reason that Sir John ought to have known better than any man what his father's views were; but Proctor has pointed out with some force that there are grounds for the opinion that this "Stratum Theory" of Sir W. Herschel (which dates back to about 1784) was in part abandoned in after years by its author. It is not a little strange that if this be the case no one should have found it out for nearly ¾ths of a century. Proctor relies especially on a passage in *Phil. Trans.*, vol. ci. p. 269. 1811. (See *Month. Not.*, vol. xxxiii. p. 541. Oct. 1873.)

[i] Plutarch, *De Placit.*, lib. iii. cap. 1.

[k] *Astronomicon*, lib. i. cap. xv.

CHAPTER VII.

THE CONSTELLATIONS.

List of those formed by Ptolemy.—Subsequent Additions.—Remarks by Herschel, &c.—Catalogue of the Constellations, with the position of, and Stars in, each.

I HAVE already referred to the constellations: in this chapter I shall catalogue them.

Ptolemy enumerates 48 constellations: 21 northern, 12 zodiacal, and 15 southern, as follows:—

Northern.

1. Ursa Minor.	The Little Bear.
2. Ursa Major.	The Great Bear.
3. Draco.	The Dragon.
4. Cepheus.	
5. Boötes, or *Arctophylax.*	The Bear Keeper.
6. Corona Borealis.	The Northern Crown.
7. Hercules, *Engonasin.*	Hercules kneeling.
8. Lyra.	The Harp.
9. Cygnus, *Gallina.*	The Swan.
10. Cassiopeia.	The Lady in her Chair.
11. Perseus.	
12. Auriga.	The Charioteer.
13. Serpentarius.	The Serpent Bearer.
14. Serpens.	The Serpent.
15. Sagitta.	The Arrow.
16. Aquila, *Vultur volans.*	The Eagle.
17. Delphinus.	The Dolphin.
18. Equuleus.	The Little Horse.
19. Pegasus, *Equus.*	The Winged Horse.
20. Andromeda.	The Chained Lady.
21. Triangulum.	The Triangle.

Zodiacal.

1. Aries.	The Ram.
2. Taurus.	The Bull.
3. Gemini.	The Twins.
4. Cancer.	The Crab.
5. Leo.	The Lion.

6. Virgo.	The Virgin.
7. Libra, *Chelæ*.	The Balance. *The claws* [of Scorpio].
8. Scorpio.	The Scorpion.
9. Sagittarius.	The Archer.
10. Capricornus.	The Goat.
11. Aquarius.	The Water Bearer.
12. Pisces.	The Fishes.

Southern.

1. Cetus.	The Whale.
2. Orion.	
3. Eridanus, *Fluvius*.	Eridanus, The River.
4. Lepus.	The Hare.
5. Canis Major.	The Great Dog.
6. Canis Minor.	The Little Dog.
7. Argo Navis.	The Ship "Argo."
8. Hydra.	The Snake.
9. Crater.	The Cup.
10. Corvus.	The Crow.
11. Centaurus.	The Centaur.
12. Lupus.	The Wolf.
13. Ara.	The Altar.
14. Corona Australis.	The Southern Crown.
15. Piscis Australis.	The Southern Fish.

Tycho Brahe (d. 1601) added—

1. Coma Berenices.	The Hair of Berenice.
2. Antinoüs.	

(Both Northern Constellations.)

Bayer (d. 1603) added—

1. Pavo.	The Peacock.
2. Toucan.	The American Goose.
3. Grus.	The Crane.
4. Phœnix.	The Phœnix.
5. Dorado, *Xiphias*.	The Sword Fish.
6. Piscis Volans.	The Flying Fish.
7. Hydrus.	The Water Snake.
8. Chamæleon.	The Chameleon.
9. Apis.	The Bee.
10. Avis Indica.	The Bird of Paradise.
11. Triangulum Australe.	The Southern Triangle.
12. Indus.	The Indian.

(All Southern.)

Royer, in 1679, added—

1. Columba Noachi.	The Dove of Noah.
2. Crux Australis.	The Southern Cross.
3. Nubes Major.	The Great Cloud.
4. Nubes Minor.	The Little Cloud.
5. Fleur-de-lys.	The Lily.

(All Southern Constellations.)

Halley, about the same period, added—

1. Robur Caroli.	Charles's Oak.

(A Southern Constellation.)

Flamsteed's maps also contain—

1. Mons Mænalus.	The Mountain Mænalus.
2. Cor Caroli.	Charles's Heart.

(Both Northern Constellations.)

Hevelius, in 1690, added—

1. Camelopardus.	The Cameleopard.
2. Canes Venatici, *Asterion et Chara.*	The Hunting Dogs.
3. Vulpecula et Anser.	The Fox and the Goose.
4. Lacerta.	The Lizard.
5. Leo Minor.	The Little Lion.
6. Lynx.	The Lynx.
7. Clypeus, or Scutum, Sobieskii.	The Shield of Sobieski.
8. Triangulum Minor.	The Little Triangle.
9. Cerberus.	

(All Northern: and)

10. Monoceros.	The Unicorn.
11. Sextans Uraniæ.	The Sextant of Urania.

(Southern Constellations.)

La Caille, in 1752, added—

1. Apparatus Sculptoris.	The Apparatus of the Sculptor.
2. Fornax Chemica.	The Chemical Furnace.
3. Horologium.	The Clock.
4. Reticulus Rhomboidalis.	The Rhomboidal Net.
5. Cœla Sculptoris.	The Sculptor's Tools.
6. Equuleus Pictoria.	The Painter's Easel.
7. Pixis Nautica.	The Mariner's Compass.
8. Antlia Pneumatica.	The Air Pump.
9. Octans.	The Octant.
10. Circinus.	The Compasses.
11. Norma, or Quadra Euclidis.	Euclid's Square.
12. Telescopium.	The Telescope.
13. Microscopium.	The Microscope.
14. Mons Mensæ.	The Table Mountain.

(All Southern Constellations.)

Le Monnier, in 1776, added—

1. Tarandus.	The Rein Deer.
2. Solitarius.	The Solitaire.

(The former in the Northern, the latter in the Southern hemisphere.)

In the same year Lalande placed Messier's name in the heavens, by forming a constellation in his honour, near Tarandus.

Poczobut, in 1777, added—

Taurus Poniatowskii.	The Bull of Poniatowski.

(Between Aquila and Serpentarius.)

Hell formed in Eridanus—

Psalterium Georgianum.	George's Lute.

And, finally, in Bode's maps we meet with—

1. Honores Frederici.	The Honours of Frederick.
2. Sceptrum Brandenburgicum.	The Sceptre of Brandenburg.
3. Telescopium Herschelii.	Herschel's Telescope.
4. Globus Aërostaticus.	The Balloon.
5. Quadrans Muralis.	The Mural Quadrant.
6. Lochium Funis.	The Log Line.
7. Machina Electrica.	The Electrical Machine.
8. Officina Typographica.	The Printing Press.
9. Felis.	The Cat.

Making in all 109 constellations. This number by no means exhausts the list of those which have been proposed by different persons. A writer in the *English Cyclopædia* very pertinently remarks: "In fact, half-a-century ago, no astronomer seemed comfortable in his position till he had ornamented some little cluster of stars of his own picking with a name of his own making."

Sir J. Herschel said: "The constellations seem to have been almost purposely named and delineated to cause as much confusion and inconvenience as possible. Innumerable snakes twine through long and contorted areas of the heavens, where no memory can follow them; bears, lions, and fishes, small and large, northern and southern, confuse all nomenclature," &c.

Many of the above smaller constellations are very properly rejected by modern uranographers, and in the list which I append, I insert those asterisms only which are generally acknowledged in the present day.

The column headed "Co-ordinates" may be thus explained. Project a line through the given R. A., and another through the given Declination, and their point of intersection will fall on a central part of the constellation, a celestial globe or map being employed.

THE NORTHERN CONSTELLATIONS.

No.	Name.	Co-ordinates. R. A. h.	m.	Decl. °	Stars of Mag. i.	ii.	iii.	iv.	v.	Total.
1	Andromeda	1	0	35	...	2	2	6	8	18
2	Aquila	19	30	10	1	...	7	3	22	33
3	Auriga	6	0	42	1	1	1	5	27	35
4	Boötes	14	35	30	1	...	8	7	19	35
5	Camelopardus	5	45	68	...	...	...	5	31	36
6	Canes Venatici	13	0	40	...	1	...	1	13	15
7	Cassiopeia	1	10	60	...	1	4	4	37	46
8	Cepheus	21	40	65	...	...	3	4	37	44
9	Clypetus Sobieskii ..	18	10	15 S.	...	...	...	...	4	4
10	Coma Berenices . ..	12	40	26	...	...	...	5	15	20
11	Corona Borealis	15	40	30	...	1	...	3	15	19
12	Cygnus	20	20	42	...	1	5	10	51	67
13	Delphinus	20	40	15	...	...	1	5	4	10
14	Draco	17	20	66	...	2	3	7	68	80
15	Equuleus	21	0	6	...	...	...	2	3	5
16	Hercules	16	45	27	...	1	6	12	46	65
17	Lacerta	20	20	44	...	...	...	2	11	13
18	Leo Minor	10	5	36	...	...	...	5	10	15
19	Lynx	7	55	50	...	...	...	4	24	28
20	Lyra	18	40	35	1	...	2	1	14	18
21	Pegasus	22	25	15	...	4	2	5	32	43
22	Perseus et Caput Medusæ	3	30	47	...	2	4	7	27	40
23	Sagitta	19	40	18	...	...	...	3	2	5
24	Serpens	15	40	10	...	1	5	8	9	23
25	Taurus Poniatowskii ..	17	50	5	...	...	...	4	2	6
26	Triangulum	2	0	32	...	...	1	1	3	5
27	Ursa Major	10	40	58	...	4	8	7	34	53
28	Ursa Minor	15	0	78	...	1	3	4	15	23
29	Vulpecula et Anser ..	20	0	25	...	...	...	2	21	23
29	Grand Total				4	22	65	132	604	827

THE ZODIACAL CONSTELLATIONS.

No.	Name.	Co-ordinates.			Stars of Mag.					
		R. A. h.	R. A. m.	Decl. °	i.	ii.	iii.	iv.	v.	Total.
1	Aries	2	30	18 N.	...	1	2	3	11	17
2	Taurus	4	0	18	1	1	4	8	44	58
3	Gemini	7	0	25	1	1	2	7	17	28
4	Cancer	8	40	20	...	...	...	5	10	15
5	Leo	10	20	15	1	3	6	11	26	47
6	Virgo	13	20	3 N.	1	1	3	10	24	39
7	Libra	15	0	15 S.	...	2	1	11	9	23
8	Scorpio	16	15	26	1	1	10	7	15	34
9	Sagittarius	18	55	32	...	...	3	10	25	38
10	Capricornus	21	0	20	...	...	2	4	16	22
11	Aquarius	22	0	9 S.	...	...	3	4	18	25
12	Pisces	0	20	10 N.	...	...	1	3	14	18
12	Grand Total				5	10	37	83	229	364

THE SOUTHERN CONSTELLATIONS.

No.	Name.	Co-ordinates.			Stars of Mag.					
		R. A. h.	R. A. m.	Decl. °	i.	ii.	iii.	iv.	v.	Total.
1	Antlia Pneumatica ..	10	0	35	...	...	...	1	6	7
2	Sculptor (App. Sculpt.)	0	30	32	...	...	...	...	13	13
3	Apus	15	20	76	...	...	...	1	6	7
4	Ara	17	0	54	...	...	3	4	8	15
5	Argo	7	40	50	2	4	9	14	104	133
6	Cœla Sculptoris	4	40	42	...	...	...	1	5	6
7	Canis Major .. .	6	45	24	1	2	4	7	13	27
8	Canis Minor	7	25	5 N.	1	...	1	...	4	6
9	Centaurus	13	0	48	2	1	5	7	39	54
10	Cetus	2	0	12	...	3	4	9	16	32

THE SOUTHERN CONSTELLATIONS—*continued.*

No.	Name.	Co-ordinates. R.A. h.	m.	Decl. °	Stars of Mag. i.	ii.	iii.	iv.	v.	Total.
11	Chamæleon	10	50	78	...	...	...	...	17	17
12	Circinus	15	0	64	...	...	...	1	1	2
13	Columba Noachi ..	5	25	35		1	1	3	10	15
14	Corona Australis ..	18	30	40	...	...	...	1	6	7
15	Corvus	12	20	18	...	1	...	2	5	8
16	Crater	11	20	15	...	...	1	2	6	9
17	Crux	12	15	60	1	2	1	2	4	10
18	Dorado	4	40	62	...	...	1	3	13	17
19	Pictor (Eq. Pict.) ..	5	25	55	...	...	...	3	14	17
20	Eridanus	3	40	30	1	1	7	18	37	64
21	Fornax (Forn. Chem.)	2	20	30	...	...	...	...	6	6
22	Grus	22	20	47	...	1	1	2	7	11
23	Horologium	3	15	57	...	...	...	...	11	11
24	Hydra	10	0	10	...	1	...	7	41	49
25	Hydrus	2	40	70	...	...	3	1	21	25
26	Indus	21	0	55	...	...	1	1	13	15
27	Lepus	5	25	20	...	...	1	9	8	18
28	Lupus	15	25	45	...	...	3	8	23	34
29	Monoceros	7	0	2	...	...	...	3	9	12
30	Mons Mensæ	5	20	75	...	...	...	1	8	9
31	Microscopium	20	40	37	...	...	...	1	4	5
32	Musca Australis	12	25	68	...	...	...	4	3	7
33	Norma	16	0	45	...	...	...	...	12	12
34	Octans	21	0	80	...	...	3	1	12	16
35	Ophiuchus	17	0	0	...	1	5	11	23	40
36	Orion	5	30	0	2	4	2	7	22	37
37	Pavo	19	20	68	...	1	2	5	19	27
38	Phœnix	1	0	50	...	2	1	4	25	32
39	Piscis Australis	21	40	32	1	...	...	3	12	16
40	Piscis Volans	7	40	68	...	...	...	1	8	9

THE SOUTHERN CONSTELLATIONS—*continued.*

No.	Name.	Co-ordinates.		Stars of Mag.					
		R. A. h. m.	Decl. °	i.	ii.	iii.	iv.	v.	Total.
41	Reticulus Rhomboidalis	4 0	62	...	...	1	1	9	11
42	Sextans	10 0	0	...	...	...	...	3	3
43	Telescopium	18 40	53	...	...	...	4	4	8
44	Toucan	23 45	66	...	...	1	3	17	21
45	Triangulum Australe	15 40	65	...	1	2	1	7	11
45	Grand Total			11	26	63	157	654	911

SUMMARY.

	Num. of Const.	Stars of Mag.					
		i.	ii.	iii.	iv.	v.	Total.
Northern	29	4	22	65	132	604	827
Zodiacal	12	5	10	37	83	229	364
Southern	45	11	26	63	157	654	911
	86	20	58	165	372	1487	2102

Argelander has given numbers which differ slightly from the foregoing. Thus:—

1st mag.	=	20	4th mag.	=	425	7th mag.	=	13,000
2nd „	=	65	5th „	=	1100	8th „	=	40,000
3rd „	=	190	6th „	=	3200	9th „	=	142,000

Grant's figures for the first 6 magnitudes are:—

18, 68, 102, 428, 1100, and 2878.

According to Argelander the number of stars visible to the naked eye at Berlin is 3256. The number, of course, increases as we approach the equator, owing to the wider expanse of heavens opened up by the diurnal movement.

C. Von Littrow[a] for the Northern hemisphere has made an enumeration as follows:—

1st mag.	=	10	5th mag.	=	1001	9th mag.	=	237,131
2nd "	=	37	6th "	=	4386	Nebulous	=	62
3rd "	=	130	7th "	=	13,823	Variable	=	64
4th "	=	312	8th "	=	58,095			

[a] *Ast. Nach.*, vol. lxxiii. No. 1741. Feb. 20, 1869.

CHAPTER VIII.

A CATALOGUE OF CELESTIAL OBJECTS.

THIS catalogue furnishes observers in any part of the world with a series of objects available for achromatic telescopes of about 3 in. aperture and 4 ft. focal length. With few exceptions, those objects which are visible in England have been examined by myself (many of them with an instrument of this size); the remainder have been selected chiefly from Sir J. Herschel's *Cape Observations*[a]. Speaking generally, double stars are characteristic of the Northern heavens; remarkable clusters and nebulæ, of the Southern; nearly all the celebrated aggregations of stars being situated South of the celestial equator, whilst important doubles are rather scarce there. The marks are to this effect:—2 stars (**) indicate objects of very special size, brilliancy, or interest; one star (*) denotes objects of less importance but still deserving of special attention.

PART I.—DOUBLE, TRIPLE, AND MULTIPLE STARS.

As a general rule, no stars are inserted which are less than 2″ or more than 60″ apart. Also, as a general rule, no principal star is included which is less than the $6\frac{1}{2}^{th}$ magnitude, and no secondary one which is less than the $7\frac{1}{2}^{th}$; but in some special cases these limitations have been disregarded, as for instance in regions where objects are sparsely scattered and an adequate number fulfilling the requisite conditions could not be obtained. Many stars, double when examined with small telescopes, appear triple or quadruple in larger ones: reckoned under the latter head they would be inappropriate in this list, but not so, regarded in the more

[a] I believe that I was the first to attempt a popular abridgement of Sir J. Herschel's Southern Catalogues.

elementary form. The magnitudes are chiefly from Smyth and Webb; the distances from various sources, especially Secchi and Dembowski. The epochs are in all cases the most recent that were accessible, but many binaries vary considerably in their distance in the course of even a few years. In double-star nomenclature, A denotes the largest star, and B, C, &c. the smaller ones in succession.

No.	Star.	R.A. 1870.	Decl. 1870.	Mags.	Distance and Notes.
		h. m. s.	° ′		″
1	β Toucani	0 25 34	−63 40·4	both 5	28
*2	π Andromedæ	0 29 56	+33 0·2	4½ and 9	36
**3	η Cassiopeiæ	0 41 9	+57 7·8	4 and 7½	6·7; 181-year binary.
*4	65 Piscium	0 42 53	+27 0·2	5½ and 6	4·2
5	* in Cassiopeiæ	0 46 38	+56 3·2	7½, 8½, 11	1·5″ 4″, multiple.
**6	ψ¹ Piscium	0 58 42	+20 46·6	both 5½	29·4
*7	α Ursæ Minoris ..	1 11 17	+88 37·0	2½ and 9½	18·4
8	37 Ceti	1 7 49	− 8 37·5	6 and 7½	51
9	6 Eridani	1 34 51	−56 51·3	both 6½	3·7
**10	γ Arietis	1 46 23	+18 39·5	4½ and 5	8.8″
*11	λ Arietis	1 50 41	+22 57·7	5½ and 8	37
**12	α Piscium	1 55 18	+ 2 8·1	5 and 6	3·5
**13	γ Andromedæ	1 55 55	+41 42·4	3½ and 5½	10·3; B also double.
*14	59 Andromedæ	2 3 4	+38 25·5	6 and 7	16
*15	ι Trianguli	2 4 49	+29 41·6	5½ and 7	3·5
*16	ι Cassiopeiæ	2 18 22	+66 49·0	4½, 7, and 9	1·8 and 7·8
17	ω Fornacis	2 28 8	−28 48·3	6½ and 8	10
*18	30 Arietis	2 29 26	+24 4·9	6 and 7	38
*19	12 Persei	2 34 3	+39 38·7	6 and 7½	22·9
**20	γ Ceti	2 36 34	+ 2 41·2	3 and 7	2·7
**21	η Persei	2 41 13	+55 21·2	5 and 8½	28
*22	220 P. II. Persei ..	2 51 36	+51 50·0	6 and 8	12·5
23	θ Eridani	2 53 20	−40 49·6	4½ and 5½	8·8
24	12 (α bis) Eridani ..	3 6 32	−29 30·3	4 and 7	5
25	f Eridani	3 43 48	−38 1·1	5 and 5½	9

No.	Star.	R.A. 1870.	Decl. 1870.	Mags.	Distance and Notes
		h. m. s.	° ′		″
*26	32 Eridani..	3 47 50	− 3 20·3	5 and 7	6·8
*27	ε Persei	3 49 7	+39 37·8	3½ and 9	8·4
*28	χ Tauri	4 14 40	+25 19·2	6 and 8	19·4
29	ψ Horologii	4 15 10	−44 34·8	5½ and 8	70
*30	τ Tauri	4 34 26	+22 42·1	5 and 8½	68
31	ι Pictoris	4 48 1	−53 41·1	6 and 7	12
*32	14 Aurigæ..	5 6 56	+32 32·2	5 and 7½	14·6
**33	β Orionis	5 8 17	− 8 21·2	1 and 9	9·5
*34	170 σ Leporis	5 13 33	−18 39·4	7 and 7½	39
*35	23 Orionis..	5 15 59	+ 3 25·1	5 and 7	32
*36	118 Tauri	5 21 15	+25 2·6	7 and 7½	5·1
*37	δ Orionis	5 25 22	− 0 23·8	2 and 7	53·3 (Secchi, 80)
**38	λ Orionis	5 27 58	+ 9 50·8	4 and 6	4·5
**39	ι Orionis	5 29 3	− 5 59·8	3½, 8½, 11	11·2 and 50
**40	σ Orionis	5 32 13	− 2 40·5	4, 8, and 7	12 and 42
**41	ζ Orionis	5 34 11	− 2 0·8	3, 6½, 10	2·4, 56 (Secchi, 1
*42	γ Leporis	5 39 3	−22 29·2	4 and 6½	93
*43	41 Aurigæ	6 1 38	+48 44·1	7 and 7½	7·8
**44	11 Monocerotis ..	6 22 31	− 6 57·0	6½, 7, and 8	7·2, 9·6 (7 and 8,
**45	12 Lyncis	6 34 44	+59 34·2	6, 6½, 7½	1·7 and 8·7
46	2193 B.A.C. Arg. Nav.	6 35 9	−48 6·8	5½ and 8	13
*47	958 Σ Lyncis	6 37 20	+55 50·7	both 6	5·1
*48	38 Geminorum	6 47 18	+13 20·6	5½ and 8	5·7
*49	301 P. VI. Lyncis ..	6 55 19	+52 57·1	6 and 6½	3·4
50	2336 B.A.C. Arg. Nav.	7 1 16	−58 59·1	6½ and 7½	2
51	γ Volantis..	7 9 50	−70 17·2	5 and 7	12
*52	19 Lyncis	7 12 14	+55 31·6	7, 8, and 8	15 and 215
**53	α Geminorum	7 26 18	+32 10·4	3 and 3½	5·7
*54	175 P. VII. Arg. Nav.	7 33 30	−26 30·4	both 6½	9·8
*55	2 Argûs Navis	7 39 30	−14 22·5	7 and 7½	17
*56	ζ Cancri	8 4 45	+18 2·4	6, 7, and 7½	0·5 and 5·4 (187
57	γ Argûs	8 5 31	+46 57·2	2 and 6	41

No.	Star.	R.A. 1870.	Decl. 1870.	Mags.	Distance and Notes.
		h. m. s.	° ′		″
*58	ϕ^2 Cancri	8 18 55	+27 21·6	6 and 6½	4·7
*59	108 P. VIII. Hydræ	8 28 56	+ 7 4·5	6 and 7	10·5
**60	124 P. VIII. Cancri ..	8 32 22	+20 0·2	7, 7½, 6½	45 and 90
61	3073 B.A.C. Arg. Nav.	8 53 47	−58 43·7	6 and 7	40
**62	38 Lyncis	9 10 44	+37 21·2	4 and 7½	2·8
**63	γ Leonis	10 12 47	+20 30·1	2 and 4	3·1
64	3613 B.A.C. Arg. Nav.	10 26 23	−44 24·1	both 7	14
*65	1474 Σ Hydræ	10 41 10	−14 34·5	7, 7, and 8	71 and 6·7
*66	54 Leonis	10 48 34	+25 26·6	4½ and 7	6·3
*67	ξ Ursæ Majoris ..	11 11 15	+32 16·0	4 and 5½	2·1
*68	ι Leonis	11 17 8	+11 14·9	4 and 7½	2·8
69	17 Crateris	11 25 49	−28 32·9	5½ and 7	10
*70	90 Leonis	11 27 57	+17 31·0	6, 7½, 9½	3·2 and 63
*71	65 Ursæ Majoris ..	11 48 19	+47 12·0	7, 9½, and 7	3·8 and 63
*72	2 Comæ Berenices ..	11 57 37	+22 11·1	6 and 7½	3·7
73	4115 B.A.C. Centauri	12 7 15	−45 0·1	5½ and 7	4
74	α Crucis	12 19 23	−62 22·7	2, 2, and 5	5, 90 [quintuple]
**75	17 Comæ Berenices ..	12 22 27	+26 38·0	5½ and 6½	wide: for low power.
76	δ Corvi	12 23 8	−15 47·4	3 and 8½	24·1
77	γ Crucis	12 23 58	−56 23·1	2 and 5	120
*78	24 Comæ Berenices ..	12 28 36	+19 5·5	5½ and 7	20·4
79	γ Virginis	12 35 4	− 0 44·2	both 4	4·6 (1873)
*80	232 P. XII. Camelop.	12 48 11	+84 7·2	6 and 6½	22
**81	12 Canum Venat. ..	12 49 57	+39 1·1	2½ and 6½	20·1
*82	54 Virginis	13 6 30	−18 8·1	7 and 7½	5·7
**83	ζ Ursæ Majoris ..	13 18 40	+55 36·3	3 and 5	{14·4; Alcor, mag. 5, is distant 11½′.
*84	f Hydræ	13 29 35	−25 49·7	6 and 7	10
*85	3 Centauri	13 44 20	−32 20·9	6 and 7	9
**86	ι Boötis	14 11 34	+51 58·0	4½ and 8	38
87	4749 B.A.C. Centauri	14 13 20	−57 51·8	5½, 8, 11	9·6 and 35
*88	69 P. XIV. Boötis ..	14 16 59	+ 9 2·4	6 and 7½	6·2
89	α Centauri	14 30 47	−60 17·9	1 and 2	15·5 (1838)
**90	π Boötis	14 34 36	+16 58·6	3½ and 6	5·7

No.	Star.	R.A. 1870.	Decl. 1870.	Mags.	Distance and Not
		h. m. s.	° ′		″
*91	54 Hydræ	14 38 30	−24 53·3	5½ and 7½	9·8
**92	ε Boötis	14 39 18	+27 37·4	3 and 7	2·9
*93	39 Boötis	14 45 17	+49 15·2	5½ and 6½	3·6
*94	ξ Boötis	14 45 22	+19 38·5	3½ and 6½	5·4
*95	212 P. XIV. Libræ ..	14 49 51	−20 48·4	6 and 7½	12
*96	44 Boötis	14 59 31	+48 9·7	5 and 6	4·7
97	κ Lupi	15 2 54	−48 14·4	5½ and 6½	27
98	μ Lupi	15 9 30	−47 23·6	6, 7, and 6	20 and 2·1
*99	μ Boötis	15 19 35	+37 50·0	4 and 8	108; B also do (0·4″: 1873).
**100	δ Serpentis	15 28 36	+10 58·5	3 and 5	3·4
*101	ζ Coronæ	15 34 29	+37 3·6	5 and 6	6·2
102	ξ Lupi	15 48 35	−33 34·9	both 6½	10
**103	51 Libræ	15 57 13	−11 0·8	4½ and 7½	7·1; A also do
**104	β Scorpii	15 57 52	−19 26·8	2 and 5½	13·6
*105	κ Herculis	16 2 12	+17 23·7	5½ and 7	30·4
*106	ν Scorpii	16 4 26	−19 7·2	4 and 7	40; B also doub
107	5435 B.A.C. Scorpii	16 11 19	−30 35·4	7 and 7½	27
*108	σ Scorpii	16 13 17	−25 16·8	4 and 9½	20·4
**109	ρ Ophiuchi	16 17 47	−23 8·7	5 and 7½	3·4; two stars make a trio.
**110	17 Draconis	16 33 10	+53 11·2	6, 6½, and 6	3·7 and 90
*111	μ Draconis	17 2 39	+54 38·7	4 and 4½	3
*112	36 Ophiuchi	17 7 20	−26 23·9	4½ and 6½	4·2
**113	α Herculis	17 8 43	+14 32·4	3½ and 5½	4·7
*114	39 Ophiuchi	17 10 5	−24 8·5	5½ and 7½	10·8
**115	ρ Herculis	17 19 12	+37 16·1	4 and 5½	3·6
**116	ν Draconis	17 29 35	+55 16·4	both 5	62
*117	ψ^1 Draconis	17 44 14	+72 12·9	5½ and 6	31
118	67 Ophiuchi	17 54 8	+ 2 56·3	4 and 8½	55
*119	95 Herculis	17 55 59	+21 35·9	5½ and 6	6·2
*120	70 Ophiuchi	17 58 52	+ 2 32·5	4½ and 7	3·8 (1873)
**121	100 Herculis	18 2 34	+26 4·8	both 7	14·1
**122	40 Draconis	18 9 46	+79 58·8	5½ and 6	20

No.	Star.	R.A. 1890.	Decl. 1890.	Mags.	Distance and Notes.
		h. m. s.	° ′		″
[illegible]	[illegible] Coronae Australis	[illegible]	[illegible]	[illegible]	22
[illegible]	[illegible] Lyrae	[illegible]	[illegible]	[illegible]	3·4 and 2·5; distance A A 207.
[illegible]	[illegible] Lyrae	[illegible]	[illegible]	[illegible]	44
[illegible]	[illegible] Lyrae	[illegible]	[illegible]	[illegible] and 9	46, 60, and 71
[illegible]	[illegible] Serpentis	[illegible]	[illegible]	[illegible]	21·7
[illegible]	[illegible] Coronae Australis	[illegible]	[illegible]	both 6	[illegible]
[illegible]	[illegible] Aquilae	[illegible]	[illegible]	6 and [illegible]	35
[illegible]	[illegible] Sagittarii	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible] Cygni	[illegible]	[illegible]	[illegible]	34·4
[illegible]	[illegible] Cygni	[illegible]	[illegible]	[illegible]	37
[illegible]	[illegible] Aquilae	[illegible]	[illegible]	[illegible]	35
[illegible]	[illegible]	[illegible]	[illegible]	both 7	43
[illegible]	[illegible]	[illegible]	[illegible]	[illegible], 9, and 8	11 and 70
[illegible]	[illegible]	[illegible]	[illegible]	6½ and 7	3·3
[illegible]	[illegible]	[illegible]	[illegible] 20·9	4, 7½, 5½	107 and 338
[illegible]	[illegible]	[illegible]	−12 56·7	3 and 4	373 [use a very low power].
[illegible]	[illegible]	[illegible]	[illegible] 19·1	4½ and 8½	7·2
[illegible]	[illegible]	[illegible]	−15 11·4	3½ and 7	205
[illegible]	[illegible]	20 [illegible] 26	−19 0·6	6 and 7	22·0
[illegible]	[illegible]	20 40 38	+15 39·6	4 and 7	11·7
[illegible]	[illegible] Pavonis	20 40 45	−62 54·5	both 6½	3·2
[illegible]	[illegible]	20 52 35	+ 3 47·9	5 and 7½	10·6; A also double (1·1″).
[illegible]	[illegible]	20 55 48	+ 6 40·2	6 and 6½	2·8
[illegible]	[illegible]	21 1 4	+38 5·1	5½ and 6	19·2 (1871)
[illegible]	[illegible]	21 16 4	+19 14·9	4 and 9	36
[illegible]	[illegible]	21 26 55	+69 59·6	3 and 8	14
[illegible]	[illegible] P. XXI. Cephei	21 34 55	+56 54·1	6, 8½, 8½	12 and 20
[illegible]	[illegible]	21 38 18	+28 9·5	5, 6, and 7½	4·6 and 217
[illegible]	[illegible] Cephei	22 0 1	+63 59·6	5 and 7	5·6
[illegible]	[illegible] P. XXII. Cephei	22 4 12	+58 39·4	6 and 6½	21
[illegible]	[illegible] Pegasi	22 17 24	+20 11·5	6½, 9, and 8	2·2 and 60
[illegible]	[illegible] Aquarii	22 19 29	−17 24·0	both 6½	8·5
[illegible]	ζ Aquarii	22 22 7	− 0 41·1	4 and 4½	3·3 (1871)

No.	Star.	R. A. 1870.	Decl. 1870.	Mags.	Distance and Notes.
		h. m. s.	° ′		″
*156	δ Cephei	22 24 20	+57 45·0	4½ and 7	41
*157	8 Lacertæ	22 30 5	+38 57·7	6½, 6½, 11, 10	two nearest, 23
*158	γ Piscis Australis ..	22 45 18	−33 33·7	5 and 8	2½
159	8046 B.A.C. Gruis ..	22 59 43	−51 23·2	7 and 7½	8
*160	107 Aquarii	23 39 15	−19 24·1	6 and 7½	5·6
*161	σ Cassiopeiæ	23 52 24	+55 1·8	6 and 8	3·1

PART II.—CLUSTERS AND NEBULÆ.

Many clusters and nebulæ are *visible* with small telescopes, which cannot in any satisfactory way be examined by such instruments. The largest and brightest only have been selected for insertion in this list; and it may as well be stated at the outset, that many of them will be found disappointing with apertures below 5 inches. Abundant light and (generally) low magnifiers are essential requisites for the satisfactory examination of all kinds of clusters and nebulæ.

In the column of Synonyms—

H refers to Sir John Herschel's new great Catalogue of 1864.
H̶ „ Sir William Herschel's Catalogues.
h „ Sir John Herschel's old Catalogue of 1833.
M „ Messier's Catalogue.
S „ Smyth's *Bedford Catalogue*.

The notes are partly selected and partly original, but those who are accustomed to observe clusters and nebulæ will be well aware how different are the impressions conveyed by the same objects to different observers using telescopes of different capabilities.

CATALOGUE OF CLUSTERS

No.	Name or Constellation.	Synonym in various Catalogues.					R.A. 1870.	Decl. 1870.
		[illegible]	H	h	M	S	h. m. s.	° ′
**1	47 Toucani	52	.. ..	2322	..	..	0 18 14	−72 48·2
**2	Andromeda.. ..	116	.. ..	50	31	24	0 35 36	+40 33·5
[illegible]	Cetus	138	1 v.	61	..	30	0 41 7	−26 0·4
4	Nubecula Minor	165	.. ..	2356	..	..	0 46 55	−74 3·3
5	Toucan . ..	193	.. ..	2375	..	..	0 57 49	−71 33·7
6	Cassiopeia	341	.. ..	126	103	55	1 24 39	+60 1·0
*7	Triangulum . ..	352	17 v.	131	[illegible]	57	1 26 30	+29 59·3
**8	Perseus	512	33 vi.	207	..	92	2 9 57	+56 32·9
*9	Perseus	584	.. ..	248	34	106	2 33 41	+42 13·2
10	Eridanus	731	.. ..	2552	..	..	3 28 41	−36 34·5
**11	η Tauri	..	.. ..	..	..	142	3 39 45	+23 41·9
**12	γ Tauri	..	.. ..	..	..	159	4 12 22	+15 18·7
13	Columba	1061	.. ..	2777	..	..	5 9 49	−40 11·6
14	Auriga	1119	.. ..	..	38	204	5 19 57	+35 43·0
15	Nubecula Major..	..	.. ..	..	..	..	5 24 0	−69 35·6
*16	Taurus	1157	. ..	357	1	212	5 26 40	+21 55·3
17	Auriga..	1166	.. ..	358	36	214	5 27 43	+34 3·0
18	Dorado	1181	.. ..	2878	..	.	5 28 32	−66 19·8
**19	Orion	1179	.. ..	360	42	216	5 28 53	− 5 28·7
**20	Orion	1184	.. ..	362	..	217	5 29 6	− 4 26·4
**21	30 Doradûs	1269	.. ..	2941	..	..	5 39 36	−69 10·0
*22	Auriga	1295	.. ..	369	37	230	5 43 46	+32 30·6
*23	Gemini	1360	.. ..	377	35	236	6 0 49	+24 20·7
24	Orion	1361	24 viii.	379	..	238	6 1 7	+13 58·3
*25	Canis Major ..	1454	.. ..	411	41	265	6 41 26	−20 36·6
26	Monoceros	1483	.. ..	425	50	276	6 56 41	− 8 9·6
27	Canis Major ..	1512	12 vii.	440	..	284	7 11 50	−15 24·4
*28	Argo Navis.. ..	1551	38 viii.	459	..	296	7 30 37	−14 11·8
29	Argo Navis.. ..	1564	.. ..	463	46	302	7 35 52	−14 31·2
30	Argo Navis . ..	1571	.. ..	3098	93	307	7 39 4	−23 34·1

AND NEBULÆ.

No.	Description.
1	Superb globular cluster, 15′ to 20′ in diameter. Central stars pale rose colour; outer ones white.
2	The great nebula; an elongated ellipse 2° long.
3	One of the finest, though faint, elliptic nebulæ, 30′ long, 5′ wide ±: some small stars involved.
4	Visible to the naked eye.
5	A highly condensed cluster, 4′ in diameter.
6	A fine field.
7	Large roundish faint oval nebula, 40′ in diameter ±; resolvable into stars.
8	The magnificent double cluster in the sword-handle of Perseus: stars 7 to 14 mag.
9	A fine group of rather large stars.
10	An oval and possibly spiral nebula.
11	The Pleiades.
12	The Hyades: a scattered group of rather large stars.
13	Bright globular cluster, 3′ in diameter.
14	Cruciform cluster. In same field, 30′ S., is 39 ♅ vii. In a rich neighbourhood.
15	Visible to the naked eye.
16	The "Crab" nebula. Large elliptical nebula, resolvable into stars.
17	A neat cluster of 9 to 11 mag. stars, near M 38, with double star in field, dist. 12″. Mags. 8 and 9.
18	Large and bright oval nebula.
19	The great nebula in Orion, with multiple star involved. The most magnificent of the nebulæ.
20	A brilliant field, 1° N. of θ.
21	Very large and irregular nebula.
22	Compact cluster of small stars.
23	Fine large cluster of 9 to 16 mag. stars. In same field to the N. is a neat cluster of small stars, 17 ♅ vi.
24	Loose cluster in the form of a trapezium, containing a pair of mags. 7½ and 8½, 2·4″ apart. 1° S. of ν.
25	Large scattered cluster, 4° below Sirius.
26	Cluster; rather more than ⅓ from Sirius to Procyon.
27	Fine large, though loose, cluster of small stars, 9 to 12 mags.
28	Bright neat cluster, with double star, 8″ dist. A bright orange star precedes.
29	Large loose cluster of small stars, 8 to 13 mag., with faint planetary nebula involved.
30	Neat cluster of small stars, 8 to 13 mag.

No.	Name or Constellation.	Synonym in various Catalogues.					R.A. 1870.	Decl. 1870.
		H	Ⱨ	h	M	S	h. m. s.	° ′
31	Argo Navis.. ..	1593	.. ..	3103	..	..	7 47 40	−38 12·7
32	Argo Navis.. ..	1619	.. ..	3111	..	..	7 56 11	−60 30·8
33	Argo Navis.. ..	1636	.. ..	3117	..	..	8 6 49	−48 52·8
34	Monoceros	1637	22 vi.	496	..	318	8 7 19	− 5 24·3
**35	Cancer..	1681	.. ..	517	44	331	8 32 45	+20 25·3
36	Cancer..	1712	.. ..	531	67	339	8 44 7	+12 17·2
37	Argo Navis.. ..	1881	.. ..	3179	..	..	9 30 29	−46 21·6
*38	Ursa Major.. ..	1949	.. ..	649	81	369	9 44 39	+69 41·0
39	Ursa Major.. ..	1950	79 iv.	..	82	369	9 44 43	+70 23·0
40	Argo Navis.. ..	2007	.. ..	3224	..	..	9 58 30	−59 29·7
**41	Sextans	2008	163 i.	668	..	373	9 58 44	− 7 5·4
42	Hydra..	2102	27 iv.	3248	..	378	10 18 31	−17 58·9
**43	η Argûs	2197	.. ..	3295	..	..	10 40 0	−58 59·9
44	Argo Navis.. ..	2308	.. ..	3315	..	..	11 0 59	−57 58·2
*45	Ursa Major.. ..	2343	.. ..	838	97	402	11 7 9	+55 43·7
*46	Ursa Major.. ..	2841	43 v.	1175	..	441	12 12 31	+48 0·9
*47	Coma Berenices..	2946	.. ..	1242	85	..	12 18 49	+18 54·5
*48	Virgo	3021	.. ..	1294	49	447	12 23 9	+ 8 42·9
*49	Virgo	3049	.. ..	1312	88	448	12 25 24	+15 8·2
50	Canes Venatici ..	3165	42 v.	1397	..	..	12 35 51	+33 15·3
*51	Canes Venatici ..	3258	.. ..	1456	94	459	12 44 45	+41 50·2
**52	κ Crucis	3275	.. ..	3435	..	..	12 45 57	−59 38·6
*53	Coma Berenices..	3321	.. ..	1486	64	467	12 50 20	+22 23·5
*54	Coma Berenices..	3453	.. ..	1558	53	474	13 6 31	+18 51·8
*55	Canes Venatici ..	3474	.. ..	1570	63	476	13 9 58	+42 43·1
**56	ω Centauri	3531	.. ..	3504	..	..	13 18 59	−46 38·0
**57	Canes Venatici ..	3572	.. ..	1622	51	484	13 24 20	+47 51·8
**58	Canes Venatici ..	3636	.. ..	1663	3	492	13 36 7	+29 1·9
**59	Libra	4083	.. ..	1916	5	538	15 11 57	+ 2 34·6
*60	Scorpio	4173	.. ..	3624	80	564	16 9 17	−22 39·1
**61	Scorpio	4183	.. ..	..	4	569	16 15 40	−26 12·6
**62	Hercules	4230	.. ..	1968	13	585	16 37 2	+36 42·5
*63	Hercules	4234	.. ..	1970	..	587	16 39 1	+24 2·7

No.	Description.
31	Superb cluster, 20′ in diameter.
32	Cluster of 200 or more stars, visible to the naked eye.
33	Large loose cluster, fully 20′ in diameter.
34	Loose bright cluster of stars, 9 to 13 mag.; double star in centre 4″ dist.
35	The fine cluster "Præsepe."
36	Large cluster of small stars, 10 to 15 mag.
37	Large rich cluster, upwards of 1° in diameter.
38	Bright elliptical nebula, 15′ long, 6′ wide ±. In same field is M 82.
39	Long narrow nebula, a bright ray, 7′ long, 1′ wide ±. In same field is M 81.
40	Large loose cluster.
41	Long narrow nebula, 5′ long, 40″ wide ±; a flashing stellar nucleus.
42	Very bright planetary nebula, 32″ diameter; bluish.
43	A very large and remarkable nebula.
44	Large scattered cluster.
45	Large planetary nebula, 3½′ to 4′ diameter.
46	Large bright elongated nebula, with stellar nucleus.
47	Round nebula; with attentive gaze, bi-nuclear; rather faint.
48	Round bright nebula, which becomes suddenly much brighter in the centre.
49	Large elliptical nebula, rather faint.
50	Very elongated nebula, rather faint, 15′ long ±, with a star close to its edge in the centre of its length.
51	Bright, large, round nebula; resolvable. Much brighter in centre.
52	Rich loose cluster, containing many coloured stars.
53	Very large, bright, elliptical nebula, with stellar nucleus.
54	Very large, very fine, globular cluster of 12-mag. stars; 3′ diameter; very compressed.
55	Large oval nebula; rather faint, with small brightish nucleus.
56	Fine globular cluster.
57	Remarkably singular double neb., the larger 6′ diam. ±, and ring-shaped. Spiral neb.
58	Very superb globular cluster of 11-mag. stars, very condensed; brighter than, but not so large as M 13.
59	Very bright superb globular cluster of stars, 11 to 15 mags.; very compressed.
60	Globular cluster of 14-mag. stars (*Herschel*): a round bright nebula in ordinary telescopes.
61	Rather loose cluster, compressed in centre, but dim. Precedes *α* Scorpii by about 1½°.
62	Large superb globular cluster of stars, 11 to 20 mags. One of the finest of its class.
63	Small bright planetary nebula, 8″ diameter. Cobalt-blue colour.

No.	Name or Constellation.	Synonym in various Catalogues.					R.A. 1870.	Decl. 1870.
		H	𝕳	h	M	S	h. m. s.	° ′
**64	Ophiuchus	4238	.. ..	1971	12	590	16 40 29	− 1 42·9
*65	Ophiuchus	4256	.. ..	1972	10	595	16 50 19	− 3 53·1
*66	Scorpio	4261	.. ..	3661	62	596	16 52 56	−29 54·7
*67	Ophiuchus	4264	.. ..	1975	19	[illegible]	16 54 36	−26 4·2
*68	Ophiuchus	4287	.. ..	1979	9	609	17 11 32	−18 23·7
**69	Hercules	4294	.. ..	..	92	611	17 13 15	+43 15·8
70	Ara	4311	.. ..	3692	..	..	17 30 6	−53 35·5
*71	Ophiuchus	4315	.. ..	1983	14	621	17 30 47	− 3 9·8
*72	Ophiuchus	..	.. ..	..	..	..	17 39 35	+ 5 45·2
*73	Ophiuchus	4346	.. ..	1990	23	626	17 49 16	−18 59·9
*74	Sagittarius	4355	{10,11,12,v. 41 iv.}	1991	20	..	17 54 28	−23 1·7
*75	Sagittarius	4361	.. ..	3722	8	..	17 55 54	−24 21·3
*76	Draco	4373	37 iv.	..	..	635	17 58 20	+66 37·9
**77	Clypeus Sobieskii	4397	.. ..	2004	24	642	18 10 48	−18 28·3
*78	Clypeus Sobieskii	4400	.. ..	2006	16	643	18 11 31	−13 49·9
*79	Clypeus Sobieskii	4401	.. ..	2007	18	644	18 12 19	−17 10·9
**80	Clypeus Sobieskii	4403	.. ..	2008	17	645	18 13 7	−16 13·4
**81	Sagittarius	4424	.. ..	2015	22	654	18 28 28	−24 0·0
**82	Antinoüs	4437	.. ..	2019	11	664	18 44 9	− 6 25·5
**83	Lyra	4447	.. ..	2023	57	669	18 48 42	+32 51·8
*84	Lyra	4485	.. ..	2036	56	688	19 11 30	+29 57·3
*85	Sagittarius	4520	.. ..	2056	71	725	19 47 55	+18 26·6
**86	Vulpecula	4532	.. ..	2060	27	729	19 53 54	+22 21·9
87	Capricornus	4608	.. ..	2090	72	766	20 46 18	−13 1·4
[illegible]	Aquarius	4628	1 iv.	2098	..	774	20 57 3	−11 52·8
**89	Pegasus	4670	.. ..	2120	15	785	21 23 39	+11 35·2
**90	Aquarius	4678	.. ..	2125	2	787	21 26 43	− 1 24·0
*91	Capricornus	4687	.. ..	2128	30	791	21 33 0	−23 45·3
**92	Lacerta	4773	75 viii.	2155	..	807	22 10 4	+49 14·1
*93	Cepheus	4957	.. ..	2238	52	837	23 18 29	+60 52·9
**94	Andromeda	4964	18 iv.	2241	..	..	23 19 38	+41 49·3
**95	Cassiopeia	5031	30 vi.	2284	..	847	23 50 28	+55 59·5

No.	Description.
64	Fine globular cluster of small stars, 10 mag., much compressed.
65	Fine large globular cluster of small stars, 10 to 15 mags., much compressed.
66	Large bright globular cluster of very small stars, 14 to 16 mags.
67	Bright globular cluster of very small stars, 16 mag., very compressed.
68	Bright globular cluster of small stars, 14 mag., 2′ diameter ±.
69	Magnificent globular cluster of small stars, condensed in centre.
70	Globular cluster.
71	Fine large globular cluster of small stars, 15 to 16 mags., 4′ diameter ±.
72	Large group of bright stars, closely *n f* β Ophiuchi. B.A.C. 6012.
73	Interesting group of small stars.
74	An open cluster of stars, superposed upon a singular trifid nebulous mass. Requires a large telescope.
75	Irregular cluster. A pretty low-power field.
76	Brilliant small planetary nebula, cobalt-blue colour; stellar nucleus; flashing light; very singular. Gaseous (?). Really requires a large aperture.
77	Globular cluster of small stars, 15 mag., in a superb field of stars.
78	A loose cluster with nebulous background.
79	Very rich field.
80	The "Horse-shoe" nebula. In ordinary telescopes more the shape of a swan.
81	Fine large globular cluster of stars, 11 to 15 mags.
82	Exceedingly beautiful aggregation of small stars of about 11 mag.
83	The annular nebula in Lyra, midway between β and γ.
84	In a fine field; a globular cluster of small stars, 11 to 14 mags., 3′ diameter.
85	Cluster of small stars, 11 to 16 mags., 3′ diameter ±.
86	The "Dumb-bell" nebula; oval in shape; major axis 9′ long, minor axis 5′ ±.
87	Large mass of very small stars, 3′ diameter. A globular cluster.
88	Small bright planetary nebula, stellar nucleus, blue colour. Similar to No. 76.
89	Fine globular cluster of very small stars, 5′ diameter ±, much compressed in centre.
90	Fine globular cluster of very small stars, 5′ diameter ±.
91	Globular cluster of small stars, 12 to 16 mags., 2′ diameter ±, rather faint.
92	A magnificent field of stars.
93	An irregular cluster of stars, 9 to 13 mags.
94	A very bright planetary neb., 12″ diam. ±; cobalt-blue colour; flashing light. Gaseous (?).
95	A superb cluster of small stars and star dust, 11 to 18 mags.

PART III.—MISCELLANEOUS OBJECTS.

The following list contains objects which are not within the scope of the two foregoing sections; to wit, coloured and variable stars of large or considerable magnitude, and, in the case of variables, of short period:—

No.	Name.	R.A. 1870.	Decl. 1870.	Mag.	Notes.
		h. m. s.	° ′		
1	* in Sculptor ..	1 21 1	−33 13·4	6	Beautiful orange-red star.
*2	* in Cetus ..	2 0 7	+ 0 49·4	7	Reddish star.
3	*o* Ceti	2 12 47	− 3 34·1	var.	Max. mag. 2; generally invisible at minimum. Period, 330d. Epoch of max.
4	*α* Ceti	2 55 28	+ 3 34·7	2½	Fine orange star, with a blue companion.
*5	*β* Persei	2 59 41	+40 27·2	var.	Max. mag. 2; min. 4; period, 2d 20¾h.
**6	* in Auriga ..	4 43 22	+28 18·2	8	Red star.
7	5 Orionis	4 46 36	+ 2 16·7	5½	Orange star.
**8	R Leporis	4 53 41	−15 1·0	var.	Max. mag. 6; min. 9; period 438d; an intense crimson.
9	* in Pictor ..	5 39 37	−46 30·9	8	Vivid red star.
**10	* in Gemini ..	6 18 0	+14 47·5	7	Reddish yellow star.
**11	2139 B.A.C. Aur.	6 27 33	+38 32·7	6	Orange star.
12	3121 B.A.C. Arg.	9 2 20	−25 20·1	4½	Deep crimson.
**13	R Leonis	9 40 34	+12 1·8	var.	Max. mag. 5; min. 10; period, 312d: a ruby star.
14	2874 Brisb. Antl.	10 6 11	−34 40·9	7	Scarlet star.
15	3630 B.A.C. Antl.	10 29 26	−38 53·5	6½	Extreme orange star.
16	3637 B.A.C. Hyd.	10 31 9	−12 42·6	6·5	
*17	R Crateris	10 54 9	−17 37·5	var.	Intense scarlet star; follows *α* 42½s and 1′ S.
18	* in Crux	12 39 49	−58 59·0	8½	Intense blood-red star; in the field with *β* Crucis, a white star.
*19	* in Boötes ..	14 18 12	+26 17·9	7½	Vivid red star.
**20	*β* Libræ	15 10 0	− 8 54·2	2½	Beautiful pale-green star.
21	* in Apus	15 11 46	−75 27·5	7	Very high red star.
**22	*α* Scorpii	16 21 25	−26 8·5	1	Fiery-red star.
*23	* in Ophiuchus	17 51 31	+ 2 44·3	7½	Very fine orange star.

No.	Name.	R.A. 1870.	Decl. 1870.	Mag.	Notes.
		h. m. s.	° ′		
24	* in Sagittarius	19 26 51	−16 39·2	7	Deep scarlet star.
25	η Aquilæ	19 45 51	+ 0 40·4	var.	Max. mag. 3·6; min. 4·7; period, 7·17d.
*26	* in Sagittarius	19 58 58	−27 35·7	7½	Fine ruby star.
*27	* in Capricornus	20 9 28	−21 43·9	6½	Pure ruby star.
28	* in Indus ..	21 12 27	−70 16·9	6	Ruby-orange star.
**29	* in Cygnus ..	21 38 58	+37 16·1	8½	Extremely intense ruby star.
**30	μ Cephei	21 39 31	+58 11·1	var.	Max. mag. 4; min. 6; period, 5 or 6 years: "very fine deep garnet."
31	δ Cephei	22 24 21	+57 45·0	var.	Max. mag. 3·7; min. 4·8; period, 5·36d.

CHAPTER IX.

A CATALOGUE OF VARIABLE STARS.

IN the *Astronomical Register* for August 1864 I published a Catalogue of Variable Stars, based upon the latest information accessible; on that catalogue, which was copied into various publications, English and foreign, the present catalogue is based.

As regards the catalogue itself, the headings of the columns are sufficiently explicit, and it is only necessary to state that the symbol < signifies that the star's minimum magnitude fell below that given, but how much is unknown.

In the catalogue in its original form, I followed the precedents set by previous writers, and included various stars suspected to be variable, but all such stars have now been formed into a sub-class by themselves.

Argelander's nomenclature has been followed, but it is manifestly a very crude and unsatisfactory one, and at no very distant period will have to give place to something more artistic. Perhaps, on the whole, simple cardinal numbers, representing the order of discovery, with the syllable "var." and the name of the constellation appended, would be the most convenient and manageable system; *e.g.* "154 var. Andromedæ."

M. Schönfeld's numerous and long-continued observations of variable stars at Mannheim have been gathered up in his *Zweiter Catalog der Veränderlichen Sterne*, a sort of supplement to which, dated from Bonn, appeared in the *Ast. Nach.*, vol. lxxxvi. Nos. 2000–2001, Jan. 4, 1876. Both these sources of information have been freely drawn upon.

I must not close this introduction without acknowledging the important assistance which I have derived from the communications of Mr. G. Knott, F.R.A.S., of Cuckfield, Mr. J. Baxendell,

F.R.A.S., of Manchester, M. Schönfeld of Bonn, M. Schmidt of Athens, and Dr. Schjellerup of Copenhagen. The help afforded me by M. Schönfeld and Mr. Knott in the matter of revising proofs has been of immense value. Without their corrections the catalogue would have had small claims on the notice of astronomers.

PART I.—STARS KNOWN TO BE VARIABLE.

No.	Star.	R.A. 1870.	Decl. 1870.	Period.	Change of Magnitude.	Authority.
		h. m. s.	° ′	Days.	From to	
1	T Cassiopeiæ	0 16 12	+55 4·3	436	7 11	Krüger 1870
2	R Androm.	0 17 12	+37 51·3	404	6 12·8<	Argelander 1858
3	S Ceti	0 17 26	−10 2·9	333	7 10·7	Borrelly 1872
4	B Cassiopeiæ	0 17 36	+63 25·5			Tycho Brahe 1572
5	T Piscium	0 25 16	+13 52·9	very irreg.	9·5 11	R. Luther 1855
6	α Cassiopeiæ	0 33 9	+55 49·4		2 2·5	Birt 1831
7	S Cassiopeiæ	1 10 8	+71 55·6	615	7 13<	Argelander 1861
8	S Piscium	1 10 46	+ 8 14·7	406	9 13<	Hind 1851
9	R Piscium	1 23 56	+ 2 12·6	345	7 13<	Hind 1850
10	S Arietis	1 57 40	+11 54·1	288	9 13<	C. H. Peters 1865
11	R Arietis	2 8 44	+24 27·1	186	8 12	Argelander 1857
12	o Ceti	2 12 47	− 3 34·1	330	2 10<	D. Fabricius 1596
13	S Persei	2 13 34	+57 59·4	1½ y. ±	8 9	Krüger 1873
14	R Ceti	2 19 24	− 0 45·9	167	8 12·8<	Argelander 1867
15	T Arietis	2 41 4	+16 57·9	323	8 9·5	Auwers
16	ρ Persei	2 56 51	+38 20·0	33 ?	3·4 4·2	Schmidt 1854
17	β Persei	2 59 43	+40 27·2	2·86727	2·5 4	Montanari 1669
18	R Persei	3 21 47	+35 13·2	209	8·6 12·5	Schönfeld 1861
19	λ Tauri	3 53 25	+12 7·3	3·952	3·4 4·2	Baxendell 1848
20	U Tauri	4 14 15	+19 30·2		9 10·4	Baxendell 1862

4. This is the celebrated temporary star observed by Tycho Brahe. D'Arrest has noticed a suspicious star close to this place.

6. J. F. Schmidt says he cannot detect the least trace of variability, though he has kept watch on the star for many years.

16. Period irregular.

20. Is placed by Schönfeld in his Catalogue of Probable Variables. It is a double-star (dist. 5″): one of the components is variable, but it is not possible to say which.

No.	Star.	R.A. 1870.	Decl. 1870.	Period.	Change of Magnitude.	Authority.	
		h. m. s.	° ′	Days.	From to		
21	T Tauri	4 14 25	+19 13·5	irreg.	9·2 12·8	Hind	1861
22	R Tauri	4 21 10	+ 9 52·2	325	7·4 13<	Hind	1849
23	S Tauri	4 22 5	+ 9 39·4	378	10 13<	Oudemans	1855
24	V Tauri	4 44 30	+17 19·0	170±	8·5 13<	Auwers	1871
25	R Orionis	4 51 57	+ 7 55·8	380	8·7 13<	Hind	1848
26	ε Aurigæ	4 52 38	+43 37·7			Fritsch	1821
27	R Leporis	4 53 41	−15 0·2	438	6 9	Schmidt	1855
28	μ Doradûs	5 5 47	−61 58·4	long	5 9	Moesta	1865
29	R Aurigæ	5 6 48	+53 26·2	465	6·5 12·5	Argelander	1862
30	S Orionis	5 22 35	− 4 47·8	410±	8 12<	Webb	1870
31	δ Orionis	5 25 22	− 0 23·8	irreg.	2·2 2·7	J. Herschel	1834
32	α Orionis	5 48 8	+ 7 22·8	irreg.	1 1·5	J. Herschel	1836
33	η Geminor.	6 7 2	+22 22·5	229	3 4	Schmidt	1865
34	T Monocer.	6 18 12	+ 7 9·2	27	6 7·5	Davis	1871
35	R Monocer.	6 32 4	+ 8 50·9	irreg.	9·5 11·5	Schmidt	1861
36	S (15) Monoc.	6 33 49	+10 0·7	3·4	4·9 5·4	Winnecke	1867
37	R Lyncis	6 50 34	+55 30·6	1 yr	9 12<	Krüger	1874
38	ζ Geminorum	6 56 24	+20 45·5	10·16	3·8 4·5	Schmidt	1844
39	R Geminor.	6 59 32	+22 54·1	371	6·5 13	Hind	1848
40	R Canis Min.	7 1 32	+10 13·6	335	7 12·3<	Argelander	1854
41	S Canis Min.	7 25 39	+ 8 35·6	332	7·5 12<	Hind	1856
42	T Canis Min.	7 26 46	+12 1·1	325	9 13<	Schönfeld	1865
43	S Geminor.	7 35 14	+23 45·2	294	8·2 13·5<	Hind	1848

27. This is Hind's celebrated "crimson star." It well deserves all that has been said of it, for it is a truly remarkable object. In 1855 Schmidt reported it to be gaining light and losing colour: but its colour is now [Jan. 1876] as deep a ruby as well can be.

28. The variability of this star depends on the observations of Lacaille, Brisbane, and Moesta, but Schönfeld does not think it at all clear that Moesta got hold of the same star as his predecessors.

32. Fletcher in 1852 confirmed Herschel, but much more recently J. F. J. Schmidt confidently asserts that observations extending over many years negative variability.

34. A very interesting star. The maximum falls 8d after the minimum.

35. This is the well-known variable of Schmidt which is in combination with the nebula 2 ♅ IV. (See *Ast. Nach.* vol. lv. No. 1302, April 6, 1861.)

36. Schönfeld finds the period to be very irregular.

41. Schönfeld thinks that the period is diminishing.

No.	Star.	R.A. 1870.	Decl. 1870.	Period.	Change of Magnitude.	Authority.
		h. m. s.	° ′	Days.	From to	
44	T Geminor.	7 41 30	+24 3·3	228	8·5 13·5<	Hind 1848
45	U Geminor.	7 47 23	+22 20·5	irreg.	9 13·5<	Hind 1855
46	R Cancri	8 9 24	+12 7·4	354	6 11·7<	Schwerd 1829
47	V Cancri	8 14 18	+17 41·7	272	7 12<	Auwers 1870
48	U Cancri	8 28 19	+19 20·5	306	8·5 13·5<	Chacornac 1853
49	S Cancri	8 36 30	+19 30·0	9·48	8 10·5	Hind 1848
50	S Hydræ	8 46 47	+ 3 33·5	256	7·5 13·5	Hind 1848
51	T Cancri	8 49 14	+20 20·7	484	8 10·5	Hind 1850
52	T Hydræ	8 49 20	− 8 38·7	289	7 12<	Hind 1851
53	R Leon. Min.	9 37 46	+35 6·5	374	6·1 11<	Schönfeld 1863
54	R Leonis	9 40 34	+12 1·8	312	5 10	Koch 1782
55	R Ursæ Maj.	10 35 25	+69 27·4	303	6 12	Pogson 1853
56	η Argûs	10 40 2	−59 0·1	70 yrs	1 6	Burchell 1827
57	R Crateris	10 54 10	−17 37·5		8 9	Winnecke 1861
58	S Leonis	11 4 7	+ 6 10·1	187	9 13	Chacornac
59	T Leonis	11 31 47	+ 4 5·5		10 14<	C. H. Peters 1865
60	X Virginis	11 55 11	+ 9 47·8		7·8 10<	Peters 1871
61	R Comæ Ber.	11 57 35	+19 30·3	363	8 13<	Schönfeld 1856
62	T Virginis	12 7 56	− 5 18·7	337	8 13<	Boguslawski
63	R Corvi	12 12 54	−18 32·0	318	7 11·5<	Karlinski 1867
64	T Ursæ Maj.	12 30 28	+60 12·2	255	7 12	Argelander
65	R Virginis	12 31 54	+ 7 42·2	146	6·5 10	Harding 1809
66	S Ursæ Maj.	12 38 15	+61 48·3	225	7·5 11	Pogson 1853
67	U Virginis	12 44 30	+ 6 15·7	207	7·5 12·5	Harding
68	W Virginis	13 19 19	− 2 42·1	17	8·7 10	Schönfeld 1866
69	V Virginis	13 21 6	− 2 29·7	251	8 13<	Goldschmidt 1857
70	R Hydræ	13 22 37	−22 36·4	436±	4 10	J.P.Maraldi 1704
71	S Virginis	13 26 13	− 6 31·5	374	6 12	Hind 1852
72	Z Virginis	13 27 45	−12 32·7		5 8	Schmidt 1866

45. The period of this star is subject to variations; Schönfeld thinks that it ranges between 70d and 150d.
54. "A fine rich ruby star." (MS. Jan. 20, 1865.)
72. Variability doubtful according to Schönfeld.

No.	Star	R.A. 1870.			Decl. 1870.		Period.	Change of Magnitude.		Authority.	
		h.	m.	s.	°	′	Days.	From	to		
73	T Boötis	14	8	0	+ 19	40·5		9·7	14<	Baxendell	1860
74	S Boötis	14	18	32	+ 54	24·2	272	8	13	Argelander	1860
75	R Camelop.	14	27	37	+ 84	25·2	266	8	13	Hencke	1838
76	R Boötis	14	31	27	+ 27	18·1	223	6	11·5	Argelander	1858
77	U Boötis	14	34	48	+ 28	1·4		9·5	13	Baxendell	1864
78	δ Libræ	14	54	2	− 8	0·1	2·32	4·9	6	Schmidt	1859
79	U Coronæ	15	12	53	+ 32	7·5	3·45	7·6	8·8	Winnecke	1869
80	S Libræ	15	13	57	− 19	55·0	190 ±	8	12·5 ?	Borrelly	1872
81	S Serpentis	15	15	34	+ 14	47·0	361	8	13	Harding	1828
82	S Coronæ	15	16	6	+ 31	50·2	361	6	12	Hencke	1860
83	R Coronæ	15	43	13	+ 28	33·5	irreg.	6	13	Pigott	1795
84	R Serpentis	15	44	42	+ 15	31·8	357	6	11<	Harding	1826
85	R Libræ	15	46	15	− 15	50·8	722	9	13<	Pogson	1858
86	T Coronæ	15	54	4	+ 26	17·5		2·5	9·8	Birmingham	1866
87	R Herculis	16	0	23	+ 18	43·4	319	8·5	13<	Argelander	1855
88	T Scorpii	16	9	18	− 22	39·0		7	13<	Auwers	1860
89	R Scorpii	16	9	54	− 22	37·3	223	9	13<	Chacornac	1853
90	S Scorpii	16	9	55	− 22	34·2	177	9	13<	Chacornac	1854
91	U Scorpii	16	14	59	− 17	34·5		9·5	13·5	Pogson	1863
92	U Herculis	16	20	3	+ 19	11·4	408	7	11·5	Hencke	1860
93	30 Herculis	16	24	22	+ 42	10·1	irreg.	5	6	Baxendell	1857
94	T Ophiuchi	16	26	18	− 15	51·2	186 or 359	10·5	13<	Pogson	1860
95	S Ophiuchi	16	26	47	− 16	53·1	233	8·5	13·5<	Pogson	1854
96	S Herculis	16	45	59	+ 15	9·7	303	6·3	12	Schönfeld	1856
97	Nov. Ophi.	16	52	13	− 12	41·4		4·5	13·5<	Hind	1848
98	R Ophiuchi	17	0	18	− 15	55·0	302	8	12<	Pogson	1853
99	α Herculis	17	8	43	+ 14	32·4		3·1	3·9	W. Herschel	1795
100	u Herculis	17	12	31	+ 33	14·4	38·5	4·6	5·4	Schmidt	1869

77. Variability doubtful according to Schönfeld.
91. Position not well determined.
93. Schönfeld calls this star g Herculis.
97. This is Hind's well-known star which suddenly blazed out in Ophiuchus, in the spring of 1848, concerning which see *Month. Not.* vol. viii. p. 146, April 1848.
100. Near the epoch of minimum Schmidt has noticed curious fluctuations of light in a period of 12 hours.

No.	Star.	R.A. 1870.	Decl. 1870.	Period.	Change of Magnitude.	Authority.
		h. m. s.	° ′	Days.	From to	
101	Nov. Ophi.	17 22 51	−21 22·1	13 m.		D. Fabricius 1604
102	X Sagittarii	17 39 22	−27 46·6	7·011	4 5·5	Schmidt 1866
103	γ^1 Sagittarii	17 56 43	−29 35·0	7·593	5 6	Schmidt 1866
104	T Herculis	18 4 11	+31 0·0	165	7 12	Argelander 1857
105	T Serpentis	18 22 28	+ 6 13·0	342	9 12·8<	Baxendell 1860
106	V Sagittarii	18 23 46	−18 20·9		7 9	Quirling 1865
107	U Sagittarii	18 24 14	−19 12·8	6·745	7 8	Schmidt 1866
108	T Aquilæ	18 39 30	+ 8 36·6	4 mth ±	8·8 9·5	Winnecke 1860
109	R. Clyp. Sob.	18 40 33	− 5 50·5	71	5 8·5	Pigott 1795
110	β Lyræ	18 45 17	+33 12·7	12·912	3·5 4·5	Goodricke 1784
111	13 Lyræ	18 51 23	+43 46·6	46	4·2 4·6	Baxendell 1856
112	*z* Cor. Aust.	18 52 24	−37 7·4	6·2	10 11·5	Schmidt 1866
113	R Cor. Aust.	18 53 9	−37 7·6	54	10 12·5<	Schmidt 1866
114	R Aquilæ	19 0 7	+ 8 2·1	345	6·5 11	Argelander 1856
115	T Sagittarii	19 8 43	−17 11·7	381	7·6 12<	Pogson 1863
116	R Sagittarii	19 9 4	−19 32·0	270	7 13<	Pogson 1858
117	S Sagittarii	19 11 49	−19 15·6	230	10 12·7	Pogson 1860
118	R Cygni	19 33 20	+49 54·5	425	6 14	Pogson 1852
119	11 Vulpec.	19 42 14	+26 59·8			Anthelm 1670
120	S Vulpec.	19 43 4	+26 57·9	67·5	8·5 9·5	Rogerson 1837
121	χ_2 Cygni	19 45 34	+32 35·2	406	4 13<	G. Kirch 1686
122	η Aquilæ	19 45 51	+ 0 40·4	7·1763	3·6 4·7	Pigott 1784
123	S Cygni	20 2 47	+57 36·7	322	9 13<	Argelander 1860
124	R Capric.	20 4 1	−14 39·2	347	9 13·5<	Hind 1848
125	S Aquilæ	20 5 39	+15 14·1	147	8·9 11·3	Baxendell 1863
126	R Sagittæ	20 8 8	+16 20·0	70·4	8·3 10·3	Baxendell 1859

103. Schönfeld calls this star W Sagittarii.
108. Period uncertain and irregular according to Schönfeld.
109. *Alias* R Scuti.
111. Schönfeld calls this star R Lyræ.
112. Schönfeld calls this star S Coronæ Australis.
113. Schmidt finds periods as follows:—33·5^d; 26·0^d; and 20·5^d.
119. A celebrated "temporary star."
121. Thus named by E. J. Stone to distinguish it from Flamsteed's χ.

No.	Star.	R.A. 1870.	Decl. 1870.	Period.	Change of Magnitude.		Authority.	
		h. m. s.	° ′	Days.	From	to		
127	R Delphini	20 8 39	+ 8 41·8	284	7·5	13		
128	U Cygni	20 15 35	+47 29·1	465	7	10·5	Knott	1871
129	R Cephei	20 23 41	+88 44·0	1 yr ±	5	11	Pogson	1856
130	S Capricorni	20 34 9	−19 30·8		9	11	Hind	1854
131	S Delphini	20 37 5	+16 37·4	276	8	11	Baxendell	1860
132	T Delphini	20 39 20	+15 55·7	331	8·2	13<	Baxendell	1863
133	U Capricorni	20 40 54	−15 15·6	203	10	13<	Pogson	1857
134	λ^1 Cygni	20 41 59	+33 53·9	365	5	6	Schmidt	1864
135	T Aquarii	20 43 6	− 5 37·6	203	7	12	Goldschmidt	1861
136	R Vulpec.	20 58 36	+23 18·4	137 ±	7·5	13	Argelander	1858
137	T Capricorni	21 14 50	−15 42·6	269	9	14<	Hind	1854
138	S Cephei	21 36 46	+78 2·3	485	7·5	11	Hencke	1858
139	μ Cephei	21 39 31	+58 11·1		4	6	W. Herschel	1782
140	T Pegasi	22 2 33	+11 54·2	370	9	13<	Hind	1863
141	δ Cephei	22 24 21	+57 45·0	5·3664	3·7	4·8	Goodricke	1784
142	S Aquarii	22 50 8	−21 2·1	280	8	11<	Argelander	1853
143	β Pegasi	22 57 28	+27 22·7	40 ±	2	2·5	Schmidt	1848
144	R Pegasi	23 0 7	+ 9 50·6	382	7	13·5	Hind	1848
145	S Pegasi	23 13 58	+ 8 12·5	318	7	12<	Marth	
146	R Aquarii	23 37 5	−16 0·3	388	6	11 ?	Harding	1811
147	R Cassiop.	23 51 49	+50 39·9	426	5	12<	Pogson	1853

127. Baxendell calls this S Aquilæ; 131, R Delphini; and 132, S Delphini.
129. This star is 24 Cephei of Hevelius.
130. Place uncertain.
134. Schönfeld calls this star T Cygni.
135. Though Goldschmidt in 1861, from his own observations, announced this to be a variable star, it is so marked in the XXth Berlin Star Chart (by Hencke), published previously.
139. Period very uncertain. At any rate much less than "5 or 6 years" as sometimes given. Perhaps 1¼ years or thereabouts. Schönfeld however says "far greater than 6 years."
143. Period seems to fluctuate; sometimes 36d, sometimes 43d. (Schmidt.)
144. Period results from 9 recent maxima, but it does not accord with earlier observations.

PART II.—STARS PROBABLY VARIABLE.

**** No attempt has been made to render this list exhaustive.

No.	Name.	R.A. 1870.	Decl. 1870.	Magnitude.	Authority.
		h m. s.	° ′		
1	— Ceti	0 17 12	−10 10·8		Borrelly
2	V Piscium	1 47 30	+ 8 8·5	6–9	Argelander 1863
3	112 Piscium	1 53 23	+ 2 28·5	6	Schmidt 1869
4	48 Tauri	4 8 24	+15 4·4	7	Schmidt 1871
5	— Orionis	5 23 33	− 1 8·0	9	Argelander
6	— Tauri	5 27 6	+21 51·2	8·9–11·12	Schmidt 1864
7	10527 Lalande Orionis	5 28 39	− 6 5·8		Falb 1875
8	α Argûs	6 21 4	−52 37·5	1	
9	27 Canis Majoris ..	7 8 57	−26 7·8	4½–6½	Gore 1875
10	— Monocerotis ..	7 23 8	−10 3·5		Birmingham 1875
11	— Geminorum	7 47 41	+22 20·5	11	Knott
12	— Leonis	10 17 5	+14 39·6	9–12	C. H. F. Peters 1873
13	49 Leonis	10 28 13	+ 9 19·2	5½	Schmidt 1867
14	α Ursæ Majoris ..	10 55 42	+62 27·2	1·5–2	Lalande 1786
15	δ Ursæ Majoris ..	12 8 59	+57 25·3		Schmidt
16	60 B Canum Venat.	12 39 1	+46 9·0	6	Schmidt 1872
17	— Virginis	13 23 39	− 8 56·1	8	Hind
18	η Ursæ Majoris ..	13 42 24	+49 57·8	1·5–2	Lalande 1786
19	υ Boötis	13 43 12	+16 26·6		Schmidt
20	34 Boötis	14 37 43	+27 4·9		Schmidt
21	β Ursæ Minoris ..	14 51 7	+74 41·2	2–2·5	Struve 1838
22	— Coronæ	15 43 11	+28 41·0	11–13	Schmidt
23	— Aquilæ	18 57 28	− 5 52·5	7	Knott
24	β Cygni	19 25 28	+27 41·3		H. Klein
25	V Capricorni	20 9 30	−21 42·9	6–8	Gore 1875

2. Alleged by Argelander to be variable, but Schönfeld does not concur in the opinion.
11. This is Winnecke's comparison star *d* for U Geminorum.
22. Comparison star for R Coronæ. Probable period 6–8 weeks.
23. A fine red star.

No.	Name.	R.A. 1870.	Decl. 1870.	Magnitude.	Authority.	
		h. m. s.	° ′			
26	9 B Delphini . ..	20 19 29	+ 9 38·2		Birmingham	
27	13 Delphini	20 41 22	+ 5 32·0	6	Schmidt	
28	14 Delphini	20 43 26	+ 7 23·0	6	Schmidt	1869
29	— Aquarii (1)	22 22 31	−10 36·0	7·8–0	Rümker	1848
30	ζ Piscis Australis ..	22 23 40	−26 44·2	6	Schmidt	1869
31	— Aquarii (2)	22 29 4	− 8 16·7	9–0	Hind	
32	303 B Aquarii	23 10 53	−12 25·2	7	Schmidt	1869
33	22743 Arg. Oel. ..	23 11 39	−19 33·0	6–9	Schulhof	1874
34	ψ^3 Aquarii	23 12 12	−10 19·2		Schmidt	
35	T Cephei	23 14 44	+55 24·1	8	Argelander	1863

29. Much uncertainty hangs over this star. In a communication published in *Month. Not.* vol. viii. p. 192, June 1848, Rümker says that he observed a star of the 7·8 mag. on July 2, 1848, close to a small one catalogued by Lalande and Bessel. Efforts to detect this star (which followed Lalande's a little S.) have failed, and the matter remains in suspense, though Goldschmidt thought he had obtained confirmatory evidence of the existence of such a star. The position given in the Catalogue is that of Lalande's star: the suspected star precedes by 1ˢ, and is about 12″ to the N. Schönfeld since 1865 has always observed the star to be invariable.

31. Possibly variable, according to Schönfeld.

CHAPTER X.

A CATALOGUE OF RED STARS[a].

THE isolated stars which exhibit various warm hues from yellow to deep brown have received less attention than they deserve. But inasmuch as recent physical discoveries have been calculated to recall to our notice Buffon's idea that the colours of the stars are merely indications of their relative states of glow, the red stars (setting a comprehensive meaning on this phrase) may reasonably be expected to arouse feelings of particular interest, because we may assume *primâ facie* that they are undergoing physical change involving combustion. This is the more likely because many of the known variable stars are either permanently or periodically reddish.

The following Catalogue is founded on the 3 existing Catalogues of Lalande (*Conn. des Temps*, An. xv), De Zach (*Corresp. Ast.*, vol. vii), and Sir J. Herschel (*Cape Obs.*), but contains many additions. A very large number of the stars have been observed by myself, and an attempt has been made to classify such according to their relative importance[b].

Many of these red stars have been examined by Secchi with a spectroscope. He finds that their spectra differ widely in character and belong to various types.

Only a few of the yellowish-red stars of J. F. J. Schmidt (of which a list is annexed to the V^th Berlin Academical Chart) are included, because his eye is so unusually sensitive that the generality

[a] Originally based on papers by Schjellerup of Copenhagen, in *Ast. Nach.*, vol. lxvii. No. 1591, June 18, 1866; and vol. lxviii. No. 1613, Oct. 30, 1866, but revised by myself with the aid of a 4-inch achromatic, 1870–3. Schjellerup published in 1874 a highly interesting and very complete catalogue of all known red stars (*Vierteljahrsschrift der astronomischen Gesellschaft*, vol. ix).

[b] For particulars of the principles on which this has been done, see the introduction to chap. viii (*ante*).

of observers would fail to recognise any sufficient amount of characteristic colour.

The names of the stars have been added by myself, and the positions brought up to 1870 by Mr. Lynn.

No.	Star.	R. A. 1870.	Decl. 1870.	Mag.	Remarks.
		h. m. s.	° ′		
*1	— Cassiopeiæ	0 2 37	+63 13·8	8·5	Red.
*2	— Andromedæ.. ..	0 13 2	+43 59·3	8·2	Intense red. ? Var.
*3	— Cassiopeiæ	0 49 44	+66 59·3	9	Orange red.
**4	— Piscium	1 9 0	+25 4·8	8	Red.
*5	— Andromedæ.. ..	1 10 17	+47 0·7	7·5	Red.
*6	— Sculptoris	1 21 0	−33 13·5	6	Most beautiful orange red.
**7	— Cassiopeiæ	1 46 11	+69 33·8	8	Very red.
*8	— Persei	1 54 27	+54 35·9	8·5	Reddish orange.
*9	— Ceti	2 0 6	+ 0 49·4	7	Very red.
**10	60 Andromedæ.. ..	2 5 4	+43 37·1	6	Deep orange.
*11	— Andromedæ.. ..	2 9 52	+44 36·3	9	Very full red.
**12	o Ceti..	2 12 47	− 3 34·1	var.	Very full sanguine.
*13	— Andromedæ.. ..	2 29 0	+56 30·3	9	Red.
*14	855 Weisse Trianguli	2 35 25	+31 52·3	7·5	Red star following the neb. 594 H 43¼ secs.
15	1014 B.A.C. Horologii	3 9 16	−57 48·6	7·5	High orange or brick red.
**16	— Ceti	3 9 56	− 6 12·5	7	Reddish orange.
*17	— Tauri	3 34 55	+14 22·4	9	Very red; almost ruby.
*18	— Persei	3 36 13	+53 29·6	9	Scarlet.
*19	— Eridani	3 37 30	−10 1·1	8	Red.
**20	1204 B.A.C. Camelop.	3 46 3	+60 43·5	5·5	Red.
*21	— Eridani	3 48 59	−15 17·4	8	Yellowish red.
*22	— Eridani	4 14 15	− 6 33·4	7·7	Reddish yellow.
**23	1342 B.A.C. Tauri ..	4 14 44	+20 30·4	6·5	Pale red.
*24	— Eridani	4 27 13	−11 3·8	6·7	Yellowish red.
**25	α Tauri	4 28 27	+16 14·8	1	Reddish orange.
*26	— Aurigæ	4 36 50	+32 40·6	8·5	Red.
**27	1457 B.A.C. Camelop.	4 37 47	+67 56·0	6·5	Very deep orange red.
**28	— Aurigæ	4 43 23	+28 18·0	8	Intense ruby.

No.	Star.	R.A. 1870.	Decl. 1870.	Mag.	Remarks.
		h. m. s.	° ′		
**29	δ^1 Orionis	4 45 11	+14 2·0	5	Reddish orange.
**30	5 Orionis	4 46 36	+ 2 16·7	5·5	Red.
**31	— Orionis	4 48 46	+ 7 34·0	7	Red.
**32	R Leporis	4 53 41	−15 0·2	var.	Hind's crimson star.
*33	— Orionis	4 55 9	+ 0 31·8	6	Yellowish red.
*34	— Orionis	4 58 41	+ 0 59·8	6·5	Red.
*35	— Orionis	4 59 56	+ 0 22·3	9	Ruby.
*36	— Orionis	5 3 26	− 0 43·7	7	Red: yellow.
*37	— Aurigæ	5 11 7	+39 12·2	7	Very ruddy; close t 1067 H.
**38	— Aurigæ	5 12 15	+34 7·8	8	Remarkably red.
**39	31 Orionis	5 23 8	− 1 11·8	5	Red.
**40	119 Tauri	5 24 36	+18 29·7	5·5	Very red.
**41	— Orionis	5 29 51	+10 57·1	7·5	Almost pale crimsoı
*42	— Orionis	5 34 30	− 3 54·8	8	Red.
*43	— Tauri	5 37 17	+24 21·7	8	Very red. ? Var.
**44	— Pictoris	5 39 36	−46 31·1	8	Like a blood drop: aı specimen of its cl
**45	α Orionis	5 48 9	+ 7 22·8	var.	Orange.
**46	π Aurigæ	5 50 17	+45 55·3	6	Rich orange.
**47	— Orionis	5 55 45	− 5 8·4	7·7	Orange red.
*48	— Geminorum	6 2 49	+26 2·3	8	Deep crimson.
49	— Pictoris	6 5 30	−52 29·5	9	Ruddy.
**50	— Geminorum	6 18 3	+14 47·4	8	Reddish yellow.
*51	— Canis Majoris ..	6 18 28	−26 59·0	8	Ruby.
*52	— Monocerotis	6 23 40	+ 0 2·5	9	Red.
*53	— Monocerotis	6 23 56	− 2 56·2	7·7	Red.
**54	2139 B.A.C. Aurigæ	6 27 36	+38 32·8	6·5	Superb orange red.
55	2196 B.A.C. Argûs ..	6 35 30	−52 49·0	6	Red.
*56	— Canis Majoris ..	6 41 26	−20 36·6	8	Chief star in neb. 4 red.
*57	1854 Rad. Camelop.	6 51 7	+70 54·9	6	Red.
58	2289 B.A.C. Argûs ..	6 52 48	−48 32·4	5·5	Red.
**59	22 Canis Majoris ..	6 56 32	−27 45·0	3·5	Red.
*60	— Monocerotis	6 56 42	− 8 9·6	8½	Red star, S of 50 M.

No.	Star.	R.A. 1870.	Decl. 1870.	Mag.	Remarks.
		h. m. s.	° ′		
*61	R Geminorum	6 59 32	+22 54·1	var.	Red.
**62	— Monocerotis ..	7 1 59	−11 43·5	7·5	Crimson red.
*63	2326 B.A.C. Camelop.	7 2 30	+82 39·6	5·4	Orange.
*64	— Geminorum	7 7 47	+22 11·6	7·3	Very red.
*65	— Monocerotis ..	7 14 49	−10 8·7		Orange-red star *p.* 1517 H.
66	— Canis Majoris ..	7 17 39	−25 30·8	7	Intense fiery red.
*67	S Canis Minoris ..	7 25 39	+ 8 35·6	var.	Strong red.
*68	σ Geminorum	7 35 11	+29 12·0	5	Reddish.
69	— Argûs	7 35 49	−31 21·1	9	Red.
**70	β Geminorum	7 37 22	+28 20·2	1·5	Orange.
71	c Puppis Argûs ..	7 40 37	−37 39·2	4·5	Orange.
72	— Argûs	7 41 34	−31 48·6	9	Very fine ruby.
73	— Argûs	7 47 5	−26 3·5	8	Red star, in middle of neb. 1589 H.
74	— Argûs	7 53 33	−49 38·3	8	Rich brick-red.
75	— Argûs	7 56 11	−60 30·8	8	Orange.
*76	R Cancri	8 9 24	+12 7·4	var.	Orange.
77	2820 B.A.C. Argûs ..	8 18 29	−37 52·1	6	Red.
**78	— Argûs	8 40 1	−27 43·7	8·5	Fiery red.
79	— Hydræ	8 40 7	+ 0 7·2	8	Orange.
80	— Argûs	8 45 35	−47 53·8	9	Ruby coloured.
*81	— Cancri	8 45 55	+19 48·7	9	Red.
**82	— Cancri	8 48 3	+17 43·4	8·5	Very fine crimson.
*83	— Hydræ	8 49 3	−10 52·6	8	Red.
84	— Argûs	8 59 53	−53 33·0	9	Ruby.
**85	3121 B.A.C. Argûs ..	9 2 20	−25 20·1	4·5	Deep crimson.
86	— Cancri	9 2 50	+31 29·7	6	Reddish orange.
87	— Argûs	9 28 57	−62 13·3	8	Very intense sanguine.
*88	R Leonis Minoris ..	9 37 46	+35 6·5	var.	Golden yellow.
**89	R Leonis	9 40 34	+12 1·8	var.	Deep red.
*90	— Hydræ	9 45 4	−22 24·5	6·5	Red.
91	— Argûs	9 50 9	−40 58·4	7·5	Scarlet.
92	— Argûs	9 55 47	−59 36·1	8·5	Scarlet.
93	18 Sextantis	10 4 29	− 7 46·6	6	Red.

No.	Star.	R.A. 1870.	Decl. 1870.	Mag.	Remarks.
		h. m. s.	° ′		
94	— Antliæ	10 6 12	−34 40·9	7	Scarlet.
95	— Argûs	10 9 59	−60 2·4	9	Ruby.
96	3630 B.A.C. Antliæ	10 29 28	−38 53·7	6·5	Extreme orange.
97	3635 B.A.C. Arg. Nav.	10 30 36	−56 53·1	5·5	Red.
**98	3637 B.A.C. Hydræ	10 31 9	−12 42·6	6·5	Red.
99	— Sextantis	10 34 24	+ 0 6·0	8·5	Red.
*100	R Ursæ Majoris ..	10 35 25	+69 27·4	var.	Fine orange.
101	— Argûs	10 39 15	−57 23·3	9	Ruby.
102	— Hydræ	10 45 18	−20 33·7	6·5	Reddish.
**103	— Crateris	10 53 6	−15 39·4	6	Red.
**104	11046 O-A Crateris ..	10 54 9	−17 37·6	8	Scarlet.
105	— Leonis	10 59 3	+ 0 6·4	9·5	Red. ? Var.
106	— Chamæleontis ..	11 5 10	−81 5·1	8	Ruby.
**107	ν Ursæ Majoris ..	11 11 28	+33 48·3	4·5	Golden yellow.
108	— Muscæ	11 33 42	−71 50·9	8·5	Fine ruby.
*109	— Leonis	11 34 27	+25 31·6	8	Red.
110	— Centauri	11 43 54	−56 27·4	8	Orange.
111	— Chamæleontis ..	12 15 44	−74 47·3	8·5	Sombre red.
112	— Virginis	12 18 35	+ 1 29·4	7·5	Red.
113	— Comæ Berenices ..	12 22 40	+29 0·8	9	Purplish red.
114	γ Crucis	12 23 58	−56 23·1	2	Red.
115	— Virginis	12 25 35	+ 5 23·5	9·5	Scarlet.
116	R Virginis	12 31 55	+ 7 42·2	var.	Pale yellowish red.
**117	4287 B.A.C. Can. Ven.	12 39 1	+46 9·0	5·5	Red.
118	— Crucis	12 39 50	−58 59·0	8·5	Intense blood-red, in field with β Crucis.
119	— Virginis	12 44 4	− 0 2·7	9	Red.
*120	— Comæ Berenices ..	12 45 54	+17 48·8	8	Tawny.
121	κ Crucis	12 45 57	−59 38·6		Extremely red.
122	— Crucis	12 46 16	−59 39·8	9	Red.
123	— Comæ Berenices ..	12 51 41	+18 28·2	8	Orange.
124	— Centauri	12 56 59	−60 44·0	9·5	Full orange.
125	γ Hydræ	13 11 50	−22 29·0	3	Red.

No.	Star.	R.A. 1870.	Decl. 1870.	Mag.	Remarks.
		h. m. s.	° ′		
*126	*i* Virginis	13 19 52	−12 1·8	5·5	Red.
127	R Hydræ	13 22 37	−22 36·4	var.	Red.
128	S Virginis	13 26 13	− 6 31·4	var.	Vivid red.
129	*υ* Boötis	13 43 13	+16 26·6	4	Reddish.
130	3105 Rad. Canum Ven.	13 47 39	+40 58·8	7	Tawny.
131	— Centauri	13 59 55	−59 6·4	8	Double: both brick-red.
132	— Centauri	14 7 35	−59 18·4	7·5	Ruby.
**133	*α* Boötis	14 9 44	+19 52·0	1	Pale yellow.
134	4775 B. A. C. Boötis	14 17 55	+ 8 40·8	6	Yellowish.
*135	— Boötis	14 18 20	+26 17·8	7·5	Vivid red.
136	— Virginis	14 22 53	− 5 24·1	8	Reddish.
137	*ρ* Boötis	14 26 14	+31 56·6	4	Red.
138	— Centauri	14 27 32	−42 48·0	9	Ruby.
139	4825 B. A. C. Boötis	14 29 20	+37 11·9	6	Reddish.
140	4976 B.A.C. Tri. Aust.	15 1 54	−69 35·2	6	Almost scarlet.
141	*δ* Lupi	15 9 55	−29 40·1	4·7	Very red.
142	— Apodis	15 11 46	−75 27·4	7	Ruby.
143	S Serpentis	15 15 34	+14 47·0	var.	Red.
144	τ^4 Serpentis	15 30 27	+15 32·0	7·5	Red; B.A.C. mag. is 6.
145	R Coronæ Borealis ..	15 43 13	+28 33·5	var.	Reddish.
146	R Serpentis	15 44 44	+15 31·8	var.	Red.
147	— Coronæ Borealis ..	15 44 54	+39 58·2	9·5	Fine deep ruby.
148	— Apodis	15 45 24	−74 6·6	9	Sombre red.
149	R Herculis	16 0 23	+18 43·4	var.	Red.
150	— Herculis	16 1 45	+22 10·4	7·5	Yellowish red.
151	— Serpentis	16 3 5	+ 1 10·0	8	Reddish.
152	— Normæ	16 8 41	−45 28·8	8·5	Ruby.
153	— Ophiuchi	16 19 30	−12 7·3	8	Dull brick-red.
154	U Herculis	16 20 3	+19 11·4	var.	Red.
155	*α* Scorpii	16 21 27	+26 8·5	1·5	Full red.
156	— Scorpii	16 32 17	−32 7·1	8	Deep red.
157	— Ophiuchi	16 42 42	+ 0 9·2	9	Reddish.
158	— Ophiuchi	16 44 29	− 5 57·1	8	Red.

No.	Star.	R.A. 1870.	Decl. 1870.	Mag.	Remarks.
		h. m. s.	° ′		
159	S Herculis	16 45 59	+15 9·7	var.	Red.
160	— Scorpii	16 46 45	−39 17·3	9	Red.
161	— Ophiuchi	16 49 30	+ 1 37·9	8·5	Red.
162	— Aræ	16 51 54	−54 52·5	9	Intense ruby red.
163	— Ophiuchi	16 52 58	− 4 1·4	8	Yellowish red.
164	α Herculis	17 8 43	+14 32·5	var.	
165	43 Ophiuchi	17 15 11	−28 0·9	6	Reddish.
166	— Scorpii	17 21 29	−35 31·9	9	Very deep red.
167	— Ophiuchi	17 22 3	−19 21·9	8·5	Ruby.
168	— Scorpii	17 31 14	−41 32·7	8	Beautiful ruby red
169	— Aræ	17 32 9	−57 39·4	8	High orange.
170	— Serpentis	17 37 18	−18 35·8	8	Remarkably red.
*171	— Ophiuchi	17 59 36	+ 7 5·3	8	Red.
*172	— Sagittarii	18 2 15	−15 18·1	8	Red.
*173	— Serpentis	18 12 49	+ 0 47·5	8	Red.
**174	6306 B.A.C. Sagittarii	18 25 18	−14 57·2	6·5	Very red.
*175	— Aquilæ	18 26 12	− 5 15·3	7·5	Reddish.
*176	— Aquilæ	18 29 7	− 6 51·0	8	Orange.
*177	— Aquilæ	18 31 32	−13 53·4	8	Red.
*178	— Serpentis	18 31 45	+11 20·3	9	Red.
*179	— Serpentis	18 39 29	+ 8 36·9	9	Plum-coloured.
**180	— Aquilæ	18 42 46	− 8 3·1	9	Very rich red.
*181	— Sagittarii	18 46 24	−22 4·4	7·5	Red.
*182	— Aquilæ	18 50 56	+ 0 17·1	9·5	Very red.
*183	— Aquilæ	18 52 37	+14 11·0	8	Red.
184	— Aquilæ	18 57 28	− 5 54·9	7½	Very red.
*185	R Aquilæ	19 0 7	+ 8 2·1	var.	Red.
*186	R Sagittarii	19 9 4	−19 32·0	var.	Red.
*187	36 Aquilæ	19 23 51	− 3 3·5	7	Bright orange.
**188	6702 B.A.C. Draconis	19 26 10	+76 18·1	6·5	Very red.
**189	— Sagittarii	19 26 51	−16 39·2	7	Remarkably red.
*190	— Aquilæ	19 38 5	+ 4 39·2	8	Reddish orange.

No.	Star.	R.A. 1870.	Decl. 1870.	Mag.	Remarks.
		h. m. s.	° ′		
*191	χ² Cygni	19 45 34	+32 35·3	var.	Reddish Orange.
*192	— Sagittarii	19 58 58	−27 35·7	7·5	Fine ruby.
193	— Pavonis	19 59 56	−60 18.6	8·5	Very red.
**194	— Capricorni	20 9 30	−21 42·9	6	"Pure ruby; the finest of my ruby stars."—H.
*195	— Delphini	20 19 29	+ 9 38·2	8·5	Pale orange.
*196	— Capricorni	20 20 0	−28 41·2	8	Ruby.
*197	— Delphini	20 51 8	+15 45·2	8	Pale orange.
198	— Aquarii	21 8 51	− 3 4·9	8·5	Red.
**199	— Cephei	21 9 31	+59 34·7	8	Orange red.
200	1725 Lac. Indi ..	21 12 27	−70 16.7	6	Ruby.
*201	— Cygni	21 37 54	+37 25·3	8	Red.
**202	— Cygni	21 38 59	+37 16·1	8·5	Extremely intense ruby.
**203	μ Cephei	21 39 31	+58 11·1	var.	Very fine deep garnet.
**204	— Aquarii	21 39 48	− 2 48·8	6·5	Red.
*205	— Cephei	21 39 39	+53 7·0	9·2	Red; in neb. [?] 4701 H.
*206	— Cygni	21 50 22	+49 53·7	9	Red.
*207	— Pegasi	21 58 5	+27 43·3	8	Pale orange.
*208	7765 B.A.C. Lacertæ	22 8 18	+39 4·2	4·5	Golden yellow.
*209	— Pegasi	22 10 56	+ 4 29·8	8	Reddish.
*210	7813 B. A. C. Cephei	22 18 15	+55 18·4	6·5	Orange.
**211	8007 B.A.C. Aquarii	22 53 3	−25 51·4	6	Red.
*212	— Piscium	22 54 38	+ 0 23·2	9	Reddish.
**213	R Pegasi	23 0 7	+ 9 50·6	var.	Decided red.
**214	55 Pegasi	23 0 27	+ 8 42·4	5·5	Golden yellow.
**215	8 Andromedæ	23 11 44	+48 18·3	5·5	Pale orange.
*216	— Cassiopeiæ	23 18 29	+60 53·0	9	Ruddy; in cluster 52 M.
*217	— Piscium	23 24 2	+ 0 9·7	8	Orange.
*218	— Pegasi	23 26 0	+23 7·7	8	Red.
**219	19 Piscium	23 39 45	+ 2 45·9	6	Very deep orange.
**220	— Ceti	23 50 26	−27 20·9	5·5	Reddish orange.
**221	R Cassiopeiæ	23 51 49	+50 39·9	var.	Vividly red.
**222	6259 Radcliffe Cassiop.	23 54 39	+59 37·9	6	Orange red, in good contrast with a blue star near.

CHAPTER XI.

A CATALOGUE OF KNOWN AND SUSPECTED BINARY STARS.

THE materials for this Catalogue have been selected from the latest and most trustworthy sources available, and no pains have been spared to make it all that it should be; but data for the compilation of such a list as this, even in an elementary form, are very scarce. Free use has been made of two important recent memoirs[a], by Messrs. J. M. Wilson and G. M. Seabroke of Rugby, and by Mr. J. Gledhill of Halifax, respectively. These three observers between them seem to have examined almost all the stars enumerated below, and as their observations were made 1870–74 they have the merit of being very recent.

The signs + and – in the last two columns indicate, it need hardly be said, that the position angle or the distance is increasing or diminishing as the case may be. A note of interrogation (?) denotes probability without certainty, but $\pm$? means that it is wholly impossible, owing to the discordances in the measures, to pronounce an opinion one way or the other.

An asterisk (*) is prefixed to various stars of which I have been unable to procure any recent measures. It may therefore be assumed that the publication of new measures of these stars is a desideratum. With respect to all the stars in Part II. not bearing an asterisk, it is to be understood that though most of the measures are rather old, yet they have been tested by Wilson, Seabroke, and Gledhill's results, and previous suspicions found to be confirmed. The older figures are retained, as better fitted for the use of observers desirous of comparing their measures with previous measures.

The "Struve" numbers, which are within brackets, refer to O. Struve's Catalogue.

[a] *Mem.* R.A.S., vol. xlii. pp. 61 and 101. 1875.

PART I. KNOWN BINARY STARS.

No.	Name of Star.	Struve's No.	R. A. 1870.	Decl. 1870.	Epoch 1800+	Mag.	Position.	Distance.
			h. m. s.	° ′			°	″
1	316 B Cephei	2	0 2 11	+78 56·2	65·7	5½, 6	295·5−	[0·38−]
2	318 B Cephei	13	0 8 53	+76 10·3	73·9	6, 6½	101·0−	0·5−
3	η Cassiopeiæ	60	0 41 15	+57 7·8	74·9	4, 7½	146·0+	5·8−
4	36 Andromedæ	73	0 47 59	+22 55·5	71·6	6, 6½	352·4+	1·35+
5	251 P. O. Piscium ..	...	0 52 44	+ 0 4·9	74·9	8, 9	312·9+	20·0+
6	42 Ceti	113	1 13 9	− 1 11·5	74·9	6, 7½	348·0+	1·45+
7	123 P. I. Piscium.. ..	138	1 29 15	+ 6 58·8	74·9	7, 7	29·9+	1·59±?
8	586 B.A.C. Piscium ..	186	1 49 10	+ 1 12·1	63·8	7½, 7½	85·1+	0·30−
9	α Piscium	202	1 55 18	+ 2 8·1	73·9	5, 6	324·2−	3·16−
10	* γ² Andromedæ B C ..	[38]	1 55 55	+41 42·4	65·7	5, 6·3	107·0−	0·59+
11	259 B Andromedæ ..	228	2 5 43	+46 52·9	73·9	7, 7	309·0+	0·77−
12	257 Σ. Persei..	257	2 15 53	+60 57·7	63·1	7, 8	183·5+	[0·40−]
13	ι Cassiopeiæ A B	262	2 18 22	+66 49·0	72·9	4½, 7	266·0−	2·25+
14	* 278 Σ. Cassiopeiæ ..	278	2 26 26	+68 43·7	57·9	8, 8½	67·6−	0·40±?
15	114 B Arietis	305	2 40 9	+18 48·5	72·0	7, 8	319·4−	2·7+
16	ε Arietis	333	2 51 46	+20 49·2	73·1	6, 6½	200·5+	1·44+
17	7 Tauri A B	412	3 26 44	+24 1·7	73·9	7½, 7½	232·0−	0·4−
18	98 P. III. Eridani ..	...	3 30 7	+ 0 9·8	73·9	6½, 9	241·3+	6·3+
19	49 Hev. Cephei	460	3 48 23	+80 19·8	74·1	5½, 6½	29·3+	0·80+
20	511 Σ. Camelopardi ..	511	4 7 1	+58 4·2	63·6	6, 7	294·0−	...
21	230 B Tauri	535	4 16 14	+11 1·3	72·1	7, 8	340·0−	1·95±?
22	2 Camelopardi	566	4 29 39	+53 12·9	73·3	5½, 8½	299·0−	1·5±?
23	577 Σ. Aurigæ	577	4 33 28	+38 15·2	73·9	7½, 8	258·6−	1·50+?
24	932 Σ. Geminorum ..	932	6 26 41	+14 50·8	74·1	8, 8½	331·0−	2·30±?
25	12 Lyncis, A B	948	6 34 44	+59 34·2	73·2	6, 6½	134·6−	1·56−
26	α Canis Majoris	...	6 39 25	−16 32·4	73·9	1, 10	65·0−	11·29±?
27	38 Geminorum	982	6 47 18	+13 20·6	74·1	5½, 8	165·7+	6·31+
28	1037 Σ. Geminorum ..	1037	7 4 42	+27 26·7	72·1	7, 7½	316·9−	1·40±?
29	α Geminorum	1110	7 26 18	+32 10·4	74·1	3, 3½	237·0−	5·7+
30	1157 Σ. Monocerotis ..	1157	7 48 1	− 2 27·5	74·1	8, 8¼	257·2−	0·88−

(1) 316 B Cephei. Epoch of distance = 1857·5.
(12) 257 Σ. Persei. Epoch of distance = 1857·5.

No.	Name of Star.	Struve's No.	R. A. 1870.	Decl. 1870.	Epoch 1800+	Mag.	Position.	Distance.
			h. m. s.	° ′			°	″
31	85 B Lyncis	1187	8 1 20	+32 36·3	72·3	7, 7½	53·5−	1·95+
32	ζ Cancri A B	1196	8 4 45	+18 2·4	74·1	6, 7	139·2−	0·50+
33	„ A C	...	...	...	72·7	6, 7½	133·0−	5·43−
34	ε Hydræ	1273	8 39 53	+ 6 53·8	74·1	4, 8½	216·7+	3·33±?
35	157 B Lyncis	1338	9 12 48	+38 44·2	74·1	6½, 7	147·8+	1·57−
36	ω Leonis	1356	9 21 29	+ 9 37·3	73·2	6½, 7½	60·8+	0·00−
37	161 P. IX. Sextantis ..	1377	9 36 42	+ 3 13·3	74·2	8, 10	139·2−	4·0±?
38	* φ Ursæ Majoris	[208]	9 43 14	+54 40·2	66·4	5, 5½	45·9+	0·24−
39	* 8 Sextantis	...	9 46 4	− 7 29·5	60·3	6, 6½	38·2−	0·50±?
40	γ Leonis	1424	10 12 47	+20 30·1	70·3	2, 4	110·6+	3·10+
41	* 145 B Leonis	1426	10 13 43	+ 7 5·0	56·1	7½, 8	271·7+	0·65±?
42	1457 Σ. Sextantis	1457	10 31 55	+ 6 24·9	72·2	7½, 8½	312·3+	0·81+
43	ξ Ursæ Majoris	1523	11 11 15	+32 16·0	73·3	4½, 5½	358·9−	0·97−
44	ι Leonis	1536	11 17 8	+11 14·9	70·0	4, 7½	72·2−	2·54+
45	191 B Virginis	1647	12 24 0	+10 45·7	74·2	7½, 8	214·2+	1·15+?
46	γ Virginis	1670	12 35 5	− 0 44·2	72·8	4, 4	160·8−	4·59+
47	1678 Σ. Comæ Berenices	1678	12 38 55	+15 5·4	74·3	6½, 7½	201·3−	32·4+
48	35 Comæ Berenices ..	1687	12 46 54	+21 57·2	71·3	5½, 8½	57·5+	1·23+?
49	42 Comæ Berenices ..	1728	13 3 40	+18 12·9	73·3	4½, 5	round+	...
50	127 P. XIII. Virginis ..	1757	13 27 39	+ 0 21·1	71·2	8, 9	63·4+	2·13±?
51	25 Canum Venaticorum	1768	13 31 53	+36 57·5	72·3	6, 7	round−	... +
52	1785 Σ. Boötis	1785	13 43 16	+27 38·0	72·9	7, 7½	201·9+	2·32−
53	1819 Σ. Virginis	1819	14 8 48	+ 3 44·2	74·4	7½, 8	23·2−	1·33+
54	1830 Σ. Boötis	1830	14 11 33	+57 16·2	73·2	8½, 9	283·9+	5·5+
55	* π Boötis	1864	14 34 36	+16 58·6	66·4	3½, 6	100·6+	5·73−
56	1876 Σ. Libræ	1876	14 39 31	− 6 50·6	73·3	8, 8	69·7+	1·27±?
57	ε Boötis	1877	14 39 18	+27 37·4	74·4	3, 7	326·1+	2·91+
58	ξ Boötis	1888	14 45 22	+19 38·5	72·9	3½, 6½	289·1−	4·65−
59	44 Boötis	1909	14 59 31	+48 9·7	73·2	5, 6	240·6+	5·3+
60	1 B Coronæ Borealis ..	1932	15 12 43	+27 18·7	74·4	6, 6½	298·6+	1·07−
61	η Coronæ Borealis ..	1937	15 17 50	+30 45·6	74·4	6, 6½	58·4+	0·93−
62	μ^2 Boötis	1938	15 19 36	+37 48·2	74·4	8, 8½	149·1−	0·70+
63	δ Serpentis	1954	15 28 36	+10 58·5	74·5	3, 5	192·9+	3·1±?

No.	Name of Star.	Struve's No.	R. A. 1870.	Decl. 1870.	Epoch 1800+	Mag.	Position.	Distance.
			h. m. s.	° ′			°	″
64	γ Coronæ Borealis ..	1967	15 37 16	+26 42·5	66.5	4, 6½	round	...
65	51 (ξ) Libræ A B.. ..	1998	15 57 13	−11 0·8	74·4	4½, 5	183·1+	1·19+
66	„ A C.. ..	...	...	...	72·8	4½, 7½	69·3−	7·14+
67	49 Serpentis	2021	16 7 14	+13 52·8	72·4	7, 7½	327·7+	3·73+?
68	2026 Σ. Herculis	2026	16 8 17	+ 7 42·4	73·4	8½, 9½	315·6−	1·51−
69	σ Coronæ Borealis A B	2032	16 9 49	+34 11·4	72·9	6, 6½	198·0+	3·12+
70	„ A C	...	...	...	71·5	6, 11	88·2−	52·6+
71	λ Ophiuchi	2055	16 24 21	+ 2 16·3	74·6	4, 6	33·6+	1·31+
72	ζ Herculis	2084	16 36 24	+31 50·1	73·5	3, 6	162·5−	1·39+
73	2106 Σ. Ophiuchi	2106	16 44 58	+ 9 37·9	73·4	6, 8	310·7−	0·51−
74	167 B Herculis	2107	16 46 42	+28 52·9	74·6	6½, 8½	208·1+	0·84±?
75	270 P. XVI. Ophiuchi	2114	16 55 44	+ 8 38·5	73·4	6½, 7½	152·2+	1·39±?
76	210 B Herculis	2120	16 59 30	+28 16·1	72·9	6½, 9	260·5−	4·02+
77	μ Draconis	2130	17 2 39	+54 38·7	74·6	4, 4½	172·3−	2·85−?
78	36 Ophiuchi	...	17 7 20	−26 23·9	72·5	4½, 6½	204·2−	4·6−?
79	δ Herculis	3127	17 9 42	+24 59·7	73·5	4, 8½	181·7+	18·8−
80	ρ Herculis	2161	17 19 12	+37 16·1	74·7	4, 5½	312·0+	4·0+
81	5910 B.A.C. Ophiuchi ..	2173	17 24 42	− 0 58·5	74·6	6, 7	331·7−	0·99−
82	μ^1 Herculis B C	2220	17 41 23	+27 48·1	74·6	10½, 10¾	100·0+	0·4−
83	τ Ophiuchi	2262	17 56 0	− 8 10·6	73·0	5, 6	248·3+	1·60+
84	70 Ophiuchi	2272	17 58 52	+ 2 32·5	73·5	4½, 7	88·8−	3·89−
85	α Lyræ	...	18 32 32	+38 39·9	74·8	1, 11	153·7+	48·5+
86	ϵ^1 (4) Lyræ	2382	18 40 0	+39 32·0	73·5	5, 6½	16·6−	3·02−?
87	ϵ^2 (5) Lyræ	2383	...	...	71·5	5, 5½	141·2−	2·70±?
88	2402 Σ. Serpentis	2402	18 43 30	+10 31·4	74·7	8, 8½	203·2+	0·97+?
89	274 P. XVIII. Aquil. A B	2434	18 56 3	− 0 53·5	74·6	9, 9	132·9−	24·0−
90	„ B C	...	...	...	73·5	9, 10½	67·5−	1·10−

(65) 51 Libræ. Perhaps the measures of A C ought rather to be put in Part II, the reality of a change not being assured. There is some confusion in the designation of this star: Dawes termed it ξ Scorpii, as also did Smyth, but in retaining the appellation "51 Libræ" I have followed the better supported usage.

(81) 5910 B.A.C. Ophiuchi. Secchi gives, as measures of Position-angle, W. Struve, 1830, 323°; Mädler, 1843, 166°; and himself, 1858, 325°, and hints at Mädler having made a mistake of 180°. Dawes gives Struve as above; many measures by himself all about 160°, and Mädler, 1854, 150°. The true explanation would seem to be that different observers had treated, some one and some the other star as A. The magnitudes of the components being nearly or quite identical, this is not matter for much surprise.

No.	Name of Star.	Struve's No.	R. A. 1870.	Decl. 1870.	Epoch 1800+	Mag.	Position.	Distance.
			h. m. s.	° ′			°	″
91	2455 Σ. Vulpeculæ ..	2455	19 1 19	+21 58·9	71·6	7½, 9½	109·7−	3·37−
92	108 P. XIX. Draconis	2509	19 15 35	+62 58·3	74·8	6½, 8	341·8−	1·00+
93	δ Cygni	2579	19 40 54	+44 48·8	73·0	3½, 9	337·9−	1·53−
94	* 400 O. Σ. Cygni ..	[400]	20 5 40	+43 34·5	61·6	7½, 8½	316·7−	0·62−?
95	2696 Σ. Delphini ..	2696	20 27 6	+ 5 0·0	73·9	8, 8½	303·9−	0·80+
96	2708 Σ. Cygni	2708	20 33 45	+38 11·1	74·7	7, 9	334·7−	21·2+
97	λ Cygni	...	20 42 20	+36 0·8	72·6	6, 7	88·5−	0·45−?
98	* 4 Aquarii	2729	20 44 32	− 6 6·7	56·8	6, 7	107·8+	0·30−
99	ε Equulei A B	2737	20 52 35	+ 3 47·9	73·7	5½, 7½	286·9−	1·15+
100	„ A C	...	...	...	73·7	5½, 7½	73·7−	10·1−?
101	61 Cygni	2758	21 1 4	+38 5·1	73·0	5½, 6	114·6+	19·38+
102	2760 Σ. Cygni	2760	21 1 27	+33 36·7	73·0	7, 8	225·1+	8·99−
103	11 O.-Arg. XXII. Ceph.	...	21 11 4	+63 52·2	73·8	7½, 7½	251·2+	0·99±?
104	20 B Pegasi..	2799	21 22 58	+10 30·6	73·7	6½, 7½	312·5−	1·28+?
105	33 P. XXII. Pegasi ..	2877	22 8 3	+16 33·0	74·8	6½, 9½	349·1+	9·7+
106	ζ Aquarii	2909	22 22 7	− 0 41·1	71·6	4, 4½	336·4−	3·31−
107	2934 Σ Pegasi	2934	22 35 35	+20 45·1	74·8	7½, 9	162·0−	1·15−?
108	π Cephei A a	...	23 3 45	+74 41·1	74·8	5, 10	19·3+	1·26+?
109	ο Cephei	3001	23 13 16	+67 24·0	74·9	6, 8½	189·9−	2·6+
110	69 P. XXIII. Aquarii	3008	23 17 2	− 9 10·4	72·8	8, 8½	248·5−	5·17−
111	8372 B.A.C. Cassiopeiæ	3062	23 59 24	+57 42·3	74·9	6½, 7½	291·0+	1·3±?

(96) 2708 Σ. Cygni. A diminution of 26° in the angle of position in 50 years, 1823–73, is clearly established. But the change in the other element is far more marked: the distance has, in like period, increased from 9·5″ to 21·0″, an amount which is very noticeable by reason of its magnitude.

(102) 2760 Σ. Cygni. In the 47 years, 1825–72, the position remained absolutely identical, but the distance diminished with extreme regularity from 14·3″ to 8·9″.

PART II. SUSPECTED BINARY STARS.

No.	Name of Star.	Struve's No.	R.A. 1870.	Decl. 1870.	Epoch 1800+	Mag.	Position.	Distance.
			h. m. s.	° ′			°	″
1	44 Σ. Andromedæ	44	0 31 8	+40 16·3	72·0	8½, 9	264·1 +	8·9 +
2	10 Arietis	208	1 56 16	+25 18·5	63·0	6, 8½	33·9 +	1·43 − ?
3	234 Σ. Cassiopeiæ	234	2 7 47	+60 44·8	63·4	8, 8½	231·4 −	0·70 −
4	84 Ceti	295	2 34 33	− 1 14·8	64·0	6, 10	324·7 −	4·63 −
5	367 Σ. Ceti	367	3 7 18	+ 0 14·3	64·0	8, 8	257·1 −	0·50 −
6	η Orionis	...	5 17 56	− 2 31·1	66·9	4, 5	86·1 ± ?	0·95 +
7	32 Orionis	728	5 23 49	+ 5 50·9	74·1	5, 6½	190·0 −	0·6 +
8	749 Σ. Tauri	749	5 29 6	+26 50·5	63·0	6½, 6½	186·4 −	0·60 − ?
9	15 Monocerotis A B ..	950	6 33 49	+10 0·9	52·1	6½, 9	212·3 −	3·21 −
10	14 Lyncis	963	6 40 36	+59 35·9	63·4	6, 6	59·5 +	0·70 −
11	μ Canis Majoris	997	6 50 8	−13 52·6	64·0	5, 8½	337·2 +	2·76 +
12	13 P. XIII. Cancri ..	1202	8 6 26	+11 14·5	63·1	8, 10	327·4 −	2·50 −
13	1216 Σ. Hydræ	1216	8 14 42	− 1 10·8	63·3	7, 7½	151·1 +	...
14	σ² Ursæ Majoris	1306	8 58 55	+67 39·7	65·8	6½, 9½	252·6 −	3·22 −
15	1316 Σ. Hydræ A B ..	1316	9 1 23	− 6 36·4	64·8	7, 11½	138·4 + ?	6·74 ± ?
16	116 B Hydræ	1348	9 17 37	+ 6 54·5	63·1	7½, 7½	328·1 −	1·66 +
17	1357 Σ. Hydræ	1357	9 21 59	− 9 25·6	56·2	7, 10½	59·5 −	7·60 + ?
18	1500 Σ. Leonis	1500	10 53 15	− 2 44·4	60·3	7½, 8	315·8 −	1·15 +
19	1781 Σ. Virginis	1781	13 39 36	+ 5 46·0	64·7	7, 8	251·7 +	1·10 +
20	238 P. XIII. Virginis ..	1788	13 48 9	− 7 25·1	64·8	6½, 7½	67·7 +	2·36 +
21	121 B Boötis	1825	14 10 34	+20 44·2	64·4	7, 8	178·8 − ?	3·89 +
22	70 P. XIV. Libræ ..	1837	14 17 42	−11 4·6	65·0	7, 8½	314·1 −	1·34 − ?
23	1863 Σ. Boötis	1863	14 33 37	+52 7·4	64·3	7, 7	95·2 −	0·77 + ?
24	ζ Boötis	1865	14 34 56	+14 17·2	64·8	4½, 5	303·2 −	1·02 −
25	260 B Boötis	1867	14 35 13	+31 50·8	49·4	8, 8½	18·5 −	1·33 − ?
26	1883 Σ. Boötis	1883	14 42 24	+ 6 30·5	63·3	7, 7½	262·7 −	0·80 +
27	1934 Σ. Boötis	1934	15 12 45	+44 15·7	64·8	8, 8½	38·1 −	6·05 + ?
28	1957 Σ. Serpentis	1957	15 29 46	+13 21·0	63·5	8, 9	155·7 −	1·53 −
29	α Scorpii A a	...	16 21 26	−26 8·5	66·0	1, 8	272·9 −	2·92 +
30	21 Ophiuchi	...	16 45 19	+ 1 25·8	65·6	6½, 8	167·6 −	1·33 − ?

(3) 234 Σ. Cassiopeiæ. Of the binary character of this object there can be little doubt.

No.	Name of Star.	Struve's No.	R. A. 1870.	Decl. 1870.	Epoch 1800+	Mag.	Position.	Distance.
			h. m. s.	° ′			°	″
31	3107 Σ. Ophiuchi	3107	16 51 34	+ 4 7·0	64·5	8, 8½	104·3 –	1·32 – ?
32	281 B Herculis	2165	17 21 11	+ 29 34·5	64·6	7½, 8½	51·2 +	7·10 +
33	2199 Σ. Draconis	2199	17 36 12	+ 55 49·7	63·0	7, 7½	101·4 –	1·65 –
34	μ^2 Herculis A B	2220	17 41 23	+ 27 48·1	66·7	4, 10½	243·9 +	31·19 +
35	73 Ophiuchi	2281	18 3 6	+ 3 58·1	54·6	6, 7½	252·0 +	1·32 –
36	417 B Herculis	2289	18 4 21	+ 16 27·0	63·0	6½, 7½	234·3 +	1·24 – ?
37	* 2384 Σ. Draconis ..	2384	18 38 36	+ 66 59·1	54·8	8, 9	332·8 +	0·35 –
38	2437 Σ. Sagittæ	2437	18 56 15	+ 18 58·8	63·0	7½, 7½	71·4 –	0·80 +
39	2454 Σ. Lyræ	2454	18 59 46	+ 30 11·8	65·3	8, 9	225·9 +	1·26 + ?
40	22 B Cygni	2525	19 21 30	+ 27 3·1	65·2	7, 7½	240·8 –	0·60 –
41	2544 Σ. Aquilæ A B ..	2544	19 30 53	+ 8 1·3	64·2	7, 9½	208·9 –	1·20 –
42	2556 Σ. Vulpeculæ ..	2556	19 33 50	+ 21 56·3	64·9	7, 7	167·7 –	...
43	2576 Σ. Cygni	2576	19 40 40	+ 33 18·4	63·3	7½, 7¾	308·8 –	3·27 – ?
44	2640 Σ. Draconis	2640	20 3 4	+ 63 31·3	41·8	7, 11	23·2 –	4·99 –
45	2744 Σ. Aquarii	2744	20 56 27	+ 1 1·3	63·2	6, 7	177·5 –	1·50 ± ?
46	2746 Σ. Cygni	2746	20 55 22	+ 38 33·3	73·6	8, 9	310·0 +	1·0 – ?
47	50 P. XXI. Cygni ..	[432]	21 9 21	+ 40 36·9	59·7	7, 7¼	126·4 – ?	1·02 – ?
48	29 B Pegasi	2804	21 26 57	+ 20 8·6	64·9	7, 8	324·5 +	2·75 +
49	37 Pegasi	2912	22 23 24	+ 3 46·4	57·1	6, 7	117·5 +	0·74 –
50	2928 Σ. Aquarii	2928	22 32 38	– 13 17·0	63·1	8, 8¼	319·3 –	4·38 –
51	219 P. XXII. Aquar. A C	2944	22 41 8	– 4 54·1	62·7	7, 8	146·6 –	50·67 –
52	2976 Σ. Piscium B C. ..	2976	23 1 26	+ 5 54·2	57·4	9½, 10	183·2 +	16·31 +
53	3046 Σ. Ceti	3046	23 50 0	– 10 12·7	63·9	8, 8¼	241·5 + ?	2·90 +
54	37 B Andromedæ	3050	23 52 48	+ 33 0·3	64·8	6, 6½	199·5 +	3·17 – ?

CHAPTER XII.

A CATALOGUE OF NEW STARS.

IN compiling my Catalogue of Uncalculated Comets (Book IV, *ante*), I was very much embarrassed in consequence of the Chinese chroniclers having intermingled with their comets proper a number of objects specifically termed by them "new stars." In some cases it was tolerably clear from internal evidence that these "new stars" were veritable comets, but in others it was impossible to express a confident opinion. Some of these uncertain objects were added to the cometary list, and others were wholly passed over, without, I am constrained to admit, any definite rule being conformed to. This manifestly involved serious drawbacks, and on due reflection, conceiving that it would be convenient to astronomers to possess a comprehensive catalogue of all recorded temporary stars, I decided to detach from the comets all objects which certainly were not comets and unite them with all objects which certainly were stars. The two lists, that is to say, this one and that in Book IV. Ch. VII. (*ante*), between them comprise, it is supposed, every comet of which an unequivocal record has been handed down to us. I cannot, however, assert that this list is equally exhaustive in regard to the temporary stars. Let it be understood, therefore, that whilst the Comet Catalogue probably contains no stars, this, most likely, does contain some comets.

I have not included objects which are commonly, and on sufficient authority, dealt with as Variable Stars and usually included in Variable Star Lists; such will be found elsewhere.

The references cited as "Biot" are to E. Biot's lists published in the *Connaissance des Temps* for 1846. The more notorious temporary stars I have not professed to speak of at length, as

they are described elsewhere in this volume. For the sake of completeness, however, it was necessary to allude to them here.

133 B.C.

In June or July an extraordinary star appeared near β, π, ρ *Scorpii*.—(Biot; Williams, *Comets*, p. 6.) Perhaps identical with the comet of 134; or this may have been the temporary star which attracted the attention of Hipparchus and led to the formation of his Catalogue.

76 B.C.

In September—October an extraordinary star appeared between α and δ *Ursæ Majoris*.—(Biot; Williams, *Comets*, p. 7.)

101 A.D.

On Dec. 30 a small yellowish-blue star appeared in the group α, γ, η, σ, κ *Leonis* (Biot); as no mention is made of any change of position it may have been merely a temporary star.—(Hind, *Companion to the Almanac*, 1859, p. 12.)

107.

On Sept. 13 a strange star appeared to the S.W. of δ, ϵ, η *Canis Majoris*.—(Biot.)

123.

In December—January an extraordinary star was seen in the region near α *Herculis* and α *Ophiuchi*.—(Biot.)

173.

On Dec. 10 a star appeared between α and β *Centauri*, and remained visible 7 or 8 months; it was like a large bamboo mat, and displayed five different colours. —(Biot.) Williams dates this object for Dec. 7, 185.—(*Comets*, p. 16.)

290.

In May a strange star was observed within the Circumpolar regions.—(Ma-tuoan-lin; Williams, *Comets*, p. 26.)

304.

In May—June a strange star was seen in the sidereal division of α Tauri.—(Biot; Williams, *Comets*, p. 27.)

369.

From the 2nd to the 7th Moon an extraordinary star was visible in the Western boundary of the circle of perpetual apparition. The 2nd Moon commenced about March 25, and the 7th about August 20.—(Biot; Williams, *Comets*, p. 29.)

386.

Between April and July a strange star was seen in the sidereal division of λ, μ, ψ *Sagittarii*.—(Biot; Gaubil; Williams, *Comets*, p. 29.)

389 ±.

A star blazed out near α *Aquilæ* as bright as *Venus*. It lasted only 3 weeks.—(Cuspianus.)

393.

Between March and October a strange star appeared in the sidereal division of μ^2 *Scorpii* or in R.A. $\pm 17^h$.—(Biot.) Williams places this object in R.A. $\pm 9\frac{1}{2}^h$.—(*Comets*, p. 30.)

561.

On Oct. 8 an extraordinary star was seen in the sidereal division of α *Crateris*.—(Biot; Williams, *Comets*, p. 36.)

577.

Pontanus (*Hist. Gelr.* iii) dates the appearance of a comet in the year that the son of Chilperic died, consequently in 577. Pingré thinks that it is the object recorded by Gregory of Tours as having appeared in the middle of the Moon on Nov. 11, during the celebration of the vigils of St. Martin, and probably a meteor.—(*Comét.* i. 323.)

827 (?).

The year is very doubtful. The Arabian astronomers, Haly and Ben Mohammed Albumazar, observed at Bagdad a star in *Scorpio* for 4 months. It was as bright as the Moon in its quarters.

829.

In November an extraordinary star was seen in ζ, θ, o, π *Canis Minoris*.—(Biot; Williams, *Comets*, p. 46.)

945.

A new star was seen near *Cassiopeia*.—(Leovitius, *De Conjunctionibus magnis*.)

1011.

On Feb. 8 an extraordinary star was seen near σ, τ, ζ, ψ *Sagittarii*.—(Biot.)

1012.

From May to August (it would seem) a star was visible in *Aries*. It was of astonishing size and dazzled the eye. It varied in size, and sometimes it was not seen at all. It lasted 3 months.—(Hepidannus, *Annales*.)

1054.

On July 4 an extraordinary star appeared to the S.E. of ζ *Tauri*. It disappeared at the end of the year.—(Biot.)

1139.

In this year an extraordinary star appeared in the division of κ *Virginis*.—(Biot.)

1174 ±.

An immense star shone by night and by day in the W. It was surrounded by numerous others all bright red in colour.—(Boethius, *Hist. Scot.* xiii.) No doubt a meteor.—(Pingré.)

1203.

Between July 28 and August 6 an extraordinary star was seen in the S.E. in the division μ^2 *Scorpii*. The colour was bluish-white resembling that of *Saturn*.—(Biot.)

1245.

A bright star appeared in Capricornus for 2 months. It was comparable to *Venus*, but was red like *Mars*.—(Albertus Stadensis; Klein, *Handbuch: Der Fixsternhimmel*, p. 102.)

1264.

A new star was seen in the vicinity of *Cepheus* and *Cassiopeia*.—(Leovitius.) Klein considers that this and the preceding are identical.

1572.

In Nov. 1572 a new star became visible in *Cassiopeia*, it lasted till March 1574. [See p. 503, *ante*.]

1584.

On July 1 a star appeared in the sidereal division of π *Scorpii*.—(Biot; Williams, *Comets*, p. 93.)

1604.

A new star appeared in *Ophiuchus*; at one time it was as bright as *Venus*. It was first seen on October 10, 1604, and last seen about the middle of October 1605. Its known duration was therefore about 12 months; but inasmuch as it was lost in consequence of coming into conjunction with the Sun its real duration might have been 14 or 15 months. At any rate in March 1606 it had become invisible. [See p. 503, *ante*.]

1612.

A new star appeared in *Aquila*.—(Riccioli, *Quelle Fromordi Meteorologica*, lib. iii. cap. 2, art. 7; Klein, *Handbuch*, vol. ii. p. 105.) Klein insinuates that this is identical with a new star dated by the Chinese for 1609.

1621.

On May 12 a reddish star was seen in the E.—(Williams, *Comets*, p. 94.)

BOOK VII.

PRACTICAL ASTRONOMY[a].

CHAPTER I.

THE TELESCOPE AND ITS ACCESSORIES.

Two kinds of telescopes.—Reflecting telescopes.—The Gregorian reflector.—The Cassegrainian reflector.—The Newtonian reflector.—The Herschelian reflector.—Nasmyth's reflector.—Browning's mountings for reflectors.—Adjustment of reflectors.—Refracting telescopes.—Spherical aberration.—Chromatic aberration.—Tests for both.—Theory of Achromatic combinations.—Tests of a good object-glass.—The Galilean refractor.—Eye-pieces.—The positive eye-piece.—The negative eye-piece.—Formulæ for calculating the focal lengths of equivalent lenses.—Kellner's eye-piece.—Berthon's Dynamometer.—Dawes's rotating eye-piece.—The diagonal eye-piece.—Dawes's solar eye-piece.—Airy's eye-piece for atmospheric dispersion.—Micrometers.—The reticulated micrometer.—The parallel-wire micrometer.—The position-micrometer.—Measurement of angles of position.—Bidder's micrometer.—Slipping-piece.—Telescope tubes.

IN the present Book I shall treat of the telescope[b], and of some of its various practical applications to astronomical purposes; with which will be incorporated other information of a kindred and useful character.

Telescopes are of 2 kinds—reflecting (or catoptric), and refracting (or dioptric): in the former an image of the object to be viewed is produced by a concave reflector, in the latter by a converging lens.

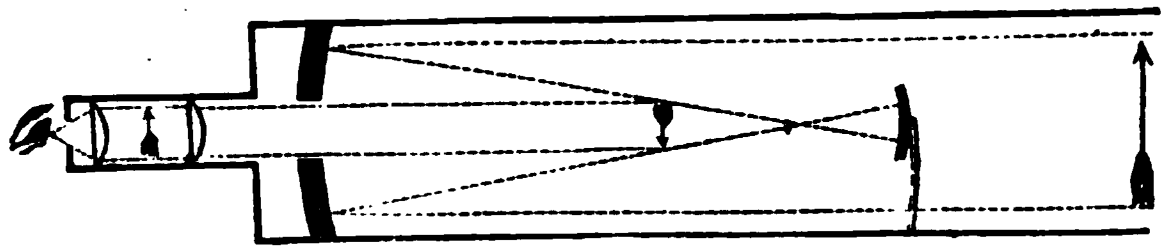
[a] On everything connected with the subject of the present Book the reader may consult with advantage Pearson's *Practical Astronomy*; Loomis's *Practical Astronomy*; and a very exhaustive modern American work, Chauvenet's *Spherical and Practical Astronomy*.

[b] τῆλε *at a distance*, and σκοπέω *I see*.

There are 4 principal constructions of reflecting telescopes :—

1. The Gregorian, invented by James Gregory, of Aberdeen, in 1663.
2. The Newtonian, invented by Sir Isaac Newton in 1669.
3. The Cassegrainian, invented by Cassegrain in 1672.
4. The Herschelian, invented by Sir William Herschel in the latter part of the last century.

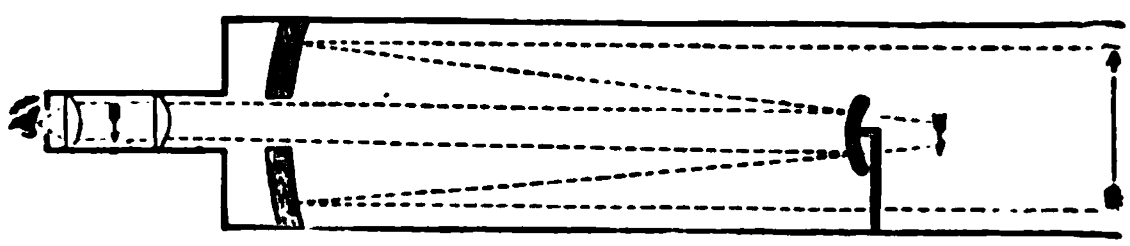
Fig. 202.



THE GREGORIAN TELESCOPE.

The *Gregorian Telescope* consists of a large concave metal speculum, in the centre of which a circular aperture is pierced. A 2nd concave speculum, with its concave surface turned in the other direction, is placed in the axis of the tube at a distance from

Fig. 203.

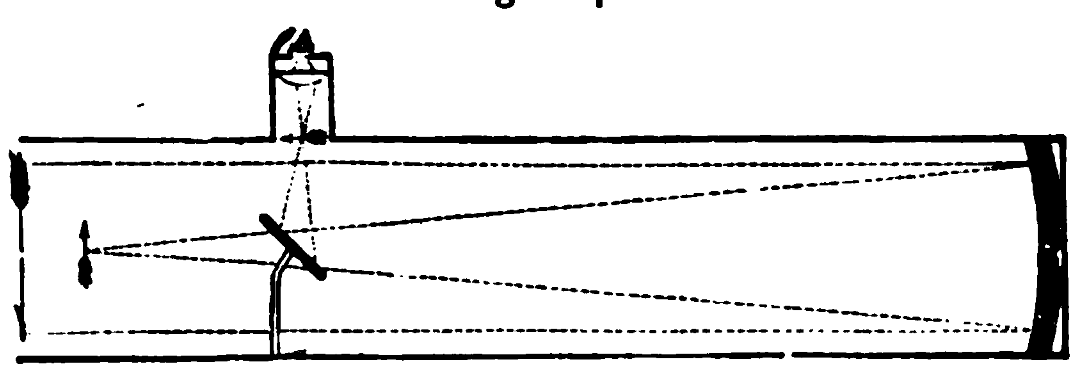


THE CASSEGRAINIAN TELESCOPE.

the larger speculum rather *greater than* the *sum* of their focal lengths. A smaller tube, carrying an eye-piece, is placed at that extremity of the larger tube where the speculum is.

The *Cassegrainian Telescope* is similar in all respects to the

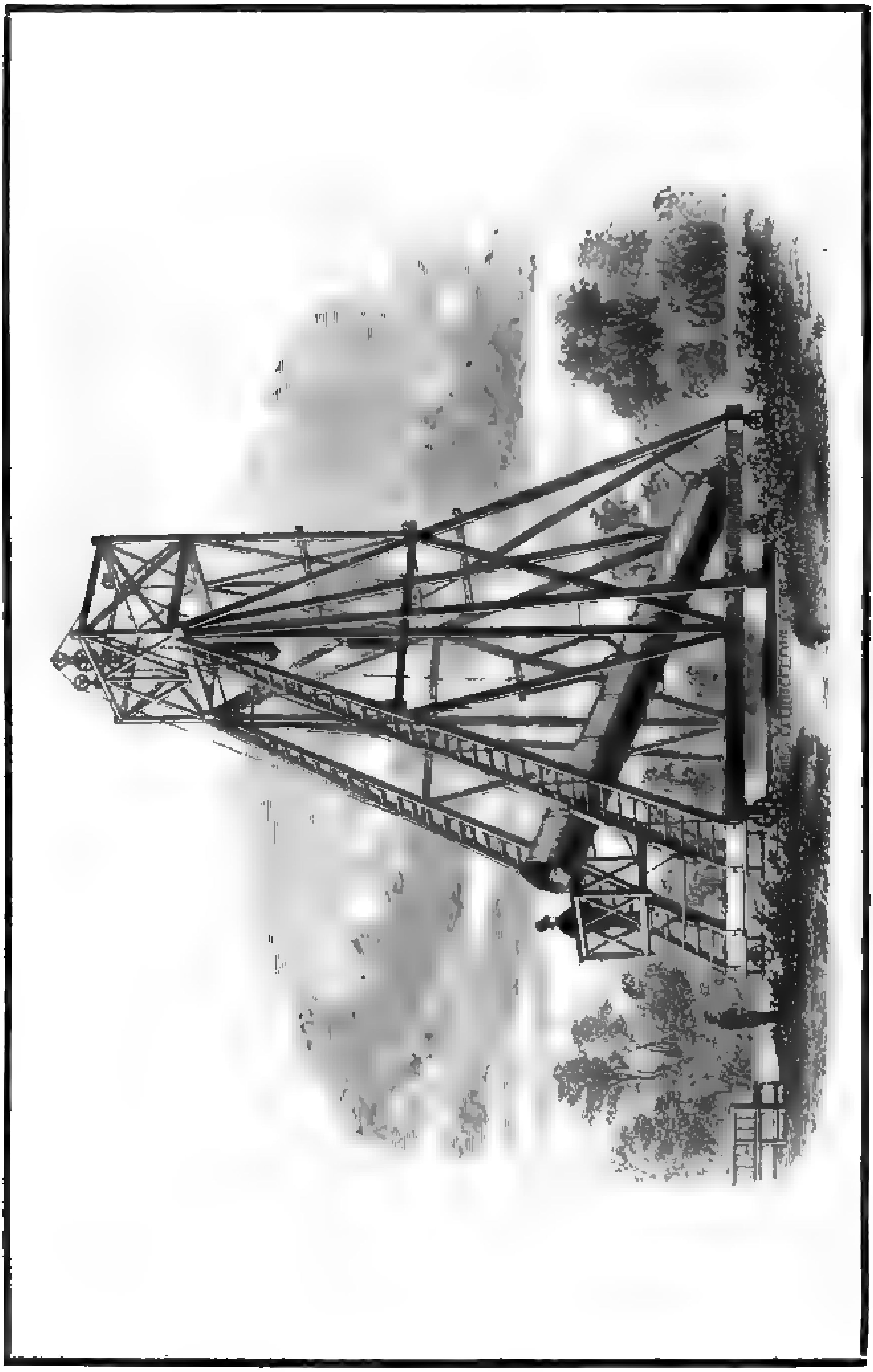
Fig. 204.



THE NEWTONIAN TELESCOPE.

Gregorian, except that the smaller speculum is convex instead of concave, and that it is placed in the tube at a distance from the larger speculum *equal to* the *difference* of their focal lengths.

Fig. 205. *Plate* XXVII.



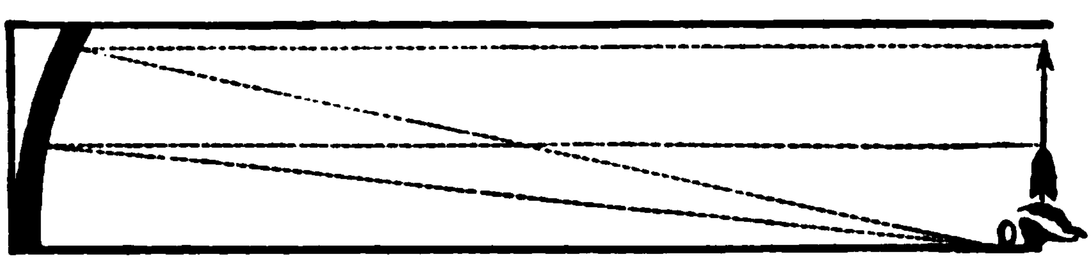
THE EARL OF ROSSE'S 6-ft. REFLECTOR.

In the *Newtonian Telescope* a large concave reflector is placed at one end of the tube. At a distance from the larger mirror, *less than* its focal length, is placed, at an angle of 45° to the optic axis of the telescope, a plane reflector, by which the rays proceeding from the object are turned to the side of the larger tube, where there is a smaller one in which an eye-piece for viewing them is placed. Instead of the plane reflector, Foucault used a prism.

In all these telescopes the central rays are lost, because in the Gregorian and Cassegrainian arrangements the central portion of the mirror is cut away, and in the Newtonian the central rays are intercepted by the plane mirror.

In the *Herschelian Telescope* the large speculum is not fixed in the tube with its diameter at right angles to the axis of the tube, but is slightly inclined to it; by this means the image of the object observed is brought to the interior edge of the tube, where it is directly examined by the eye-piece, instead of through the medium of a 2nd reflector. The advantages of this plan are,

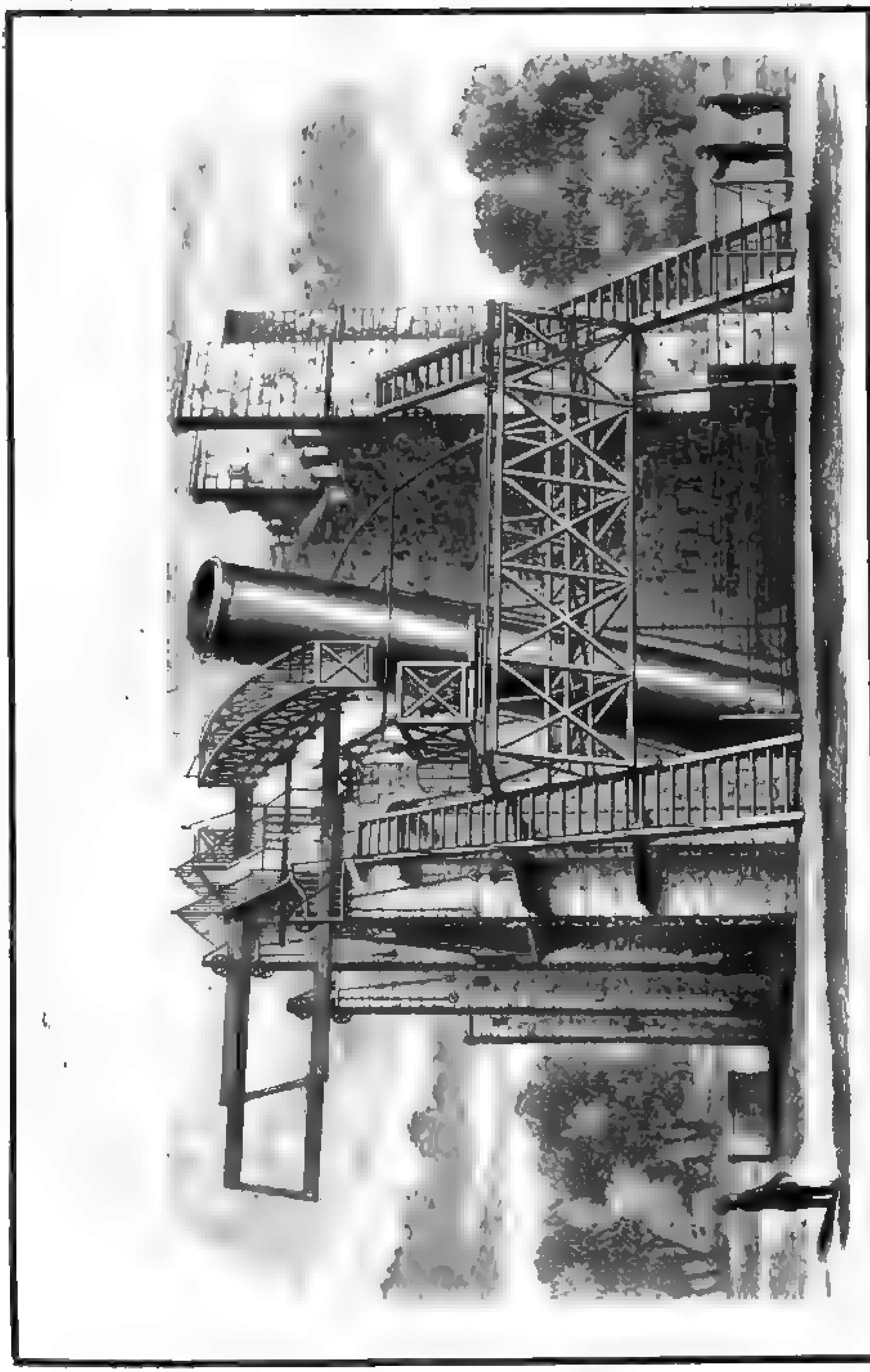
Fig. 206.



THE HERSCHELIAN TELESCOPE.

that not only can observations be made with greater ease, but a saving of light is effected by dispensing with the 2nd reflector. It was with an instrument constructed in this way that Sir W. Herschel made his numerous and important observations and discoveries, of which many have already been brought under the notice of the reader.

A modification of Newton's arrangement has been made use of with satisfactory results by Mr. James Nasmyth, the eminent machinist. The rays reflected from the great speculum are received either upon a small speculum, or upon a prism, placed in the axis of the tube between the focus and the great speculum. By this they are reflected at right angles, and the image is formed in one of the trunnions (made tubular for the purpose) on which the instrument turns. The image is then viewed in the usual way.



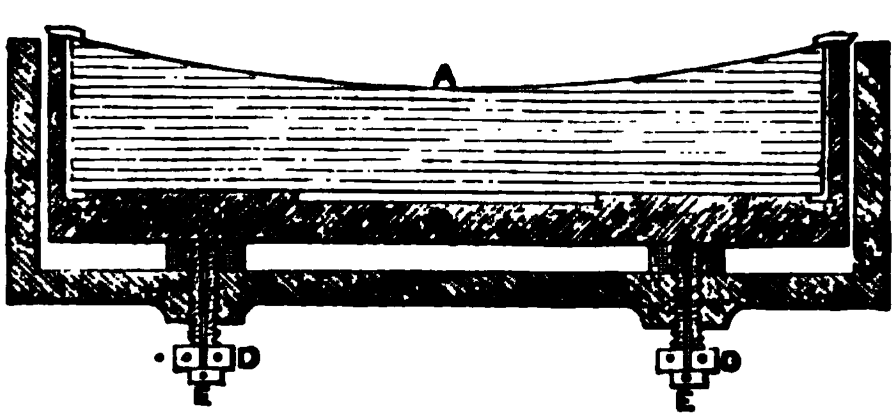
THE EARL OF ROSSE'S 6-ft. REFLECTOR.

The advantage accruing from this arrangement is that the great tube can be moved through any extent of altitude, whilst the lateral or trunnion tube, in which is placed the eye-piece, remains in one position, and thus the observer can survey any vertical circles in the sky without continually changing his station. The inventor has a reflector of this construction erected at his residence at Penshurst, the tube of which is 28 feet long and 4 feet 6 inches in diameter. The azimuthal movement is given by a turn-table similar to that used on railways for turning locomotive engines.

Reflecting telescopes were for many years but little used (always excepting a few large ones of historic note so to speak), but their employment is now greatly on the increase; and the more modern sort, having mirrors made of silvered glass instead of speculum metal, now compete with refractors in regard to efficiency balanced against lesser cost. Attention has been a good deal drawn to them of late, and With of Hereford (working originally under the direction of a very skilful amateur, the Rev. H. C. Key, M.A.), Foucault of Paris, and Steinheil of Munich, have turned out instruments which have been very favourably reported upon by competent judges. With confines his attention to the grinding of mirrors, and leaves the mounting to be done by others, in particular by Browning.

Fig. 208 is a representation of the bed employed by Browning for With's mirrors.

Fig. 208.



The bottom of the mirror A is ground to an approximately true surface, and the same thing is done with the bottom of the inner cell B, on which it rests. Parallelism is obtained by the use of the adjusting-screws D D and E E; and the mirror can be removed from the tube of the telescope and replaced with great facility without loss of adjustment. A tight-fitting brass cap closes the inner cell, and protects the silvered surface when not in use.

A reference back to figs. 202–4 will shew the small mirror in each case mounted on a single stout arm, and this has always (I believe) been the method adopted; but Browning employs 3 thin strips of chronometer-spring presented edgeways to the axis of the telescope, as in figs. 209–10. This plan of mounting the smaller

Fig. 209.

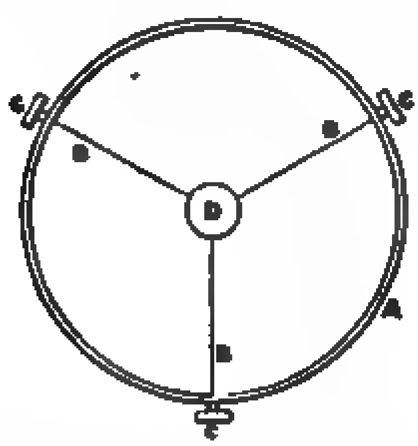
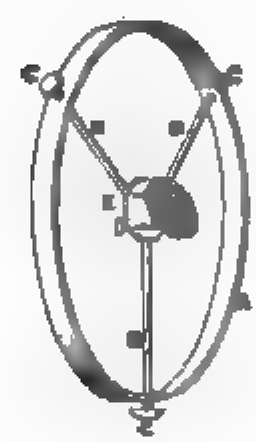


Fig. 210.



mirror has the important advantage that the 3 slender springs offer much less obstruction to the passage of the optic rays than does the one thick arm commonly used.

It may not be out of place to offer a few observations on the adjustment of Newtonian reflectors. But what I shall say must be understood as applying more particularly to silvered glass reflectors, which may be said to have superseded all others.

If the mirror has been taken out of its cell, carefully remove any dust which may have accumulated on the under side or in the cell; then screw on the ring which confines the mirror. Should the mirror be found to have any lateral motion in its cell, before screwing on the ring insert a few long slips of stout white paper between the edge of the mirror and the cell, leaving it however an easy fit. Having secured the mirror in the tube by means of the 3 milled-headed screws, the cover being on the mirror during this operation, insert into the eye-tube an eye-piece from which the lenses have been removed. Looking now through the eye-tube, shift the diagonal mirror by the screws provided for the purpose until the reflected image of the cover is seen in the centre of the diagonal mirror. To do this, loosen the milled-headed screw behind the mounting of the diagonal mirror; turn the mirror until the image of the cover appears central in one direction, and re-clamp the diagonal mirror by means of the

screw. At the back of the plate, on which the diagonal mirror turns, there is another screw. By means of this the reflected image of the cover may be made central in the other direction. On clamping this screw this adjustment should be complete. To adjust the mirror take the cover off and replace the mirror in the tube. Then move the screws at the bottom of the outside cell which contains the mirror, until, on looking through the eye-tube, the image of the diagonal mirror is seen in the centre of the reflection of the large mirror. The large hollow screws move the large mirror, and the smaller screws which run through the larger ones clamp the mirror. This clamping having been performed the adjustment should be complete, and the telescope may be directed to an object and focussed as in the case of a refractor.

The diagonal mirror itself will probably now require a little adjustment. Direct the telescope to a bright star, or, in the daytime, to some bright point of light, using an eye-piece of high power, say 50 to each inch of aperture. Observe if the image is deformed by a flare in one direction. If not, the diagonal mirror is properly adjusted. But if a flare should appear on either side of the image, that part of the diagonal mirror towards which the flare projects must be gently moved *from* the observer.

To adjust the finder, cause some well-defined and distant terrestrial object to appear in the centre of the field of the large telescope, using for the purpose a rather high power. Then looking through the finder, bisect the object with the cross-wires by turning, as may be necessary, the adjusting-screws attached to the rings which hold the finder. Repeat this adjustment several times if needs be, and finally, by the aid of a bright star in the place of a terrestrial object.

I shall not enter at any greater length into the consideration of reflecting telescopes, for though they have come a good deal into use again of late years, yet the more durable character and greater manageability of refractors, combined with the lessening in their cost brought about by modern improvements in manufacturing processes, have made them much more sought after than was the case half a century ago [c].

[c] For particulars respecting the manufacture of reflecting telescopes, see papers by the late Earl of Rosse in *Phil. Trans.*, vol. cxxx. p. 503, 1840 (Oxmantown); vol.

A refracting telescope in its simplest form consists merely of a double convex lens which forms an image of the object to be viewed (and hence termed the *object-glass*), and a second and smaller double convex lens (called the *eye-piece*), used as a simple microscope to examine the image formed by the first. For astronomical purposes the object-glass is double (sometimes triple) for the purpose of neutralising certain optical inconveniences, called *spherical* and *chromatic aberration*, and the eye-glass is generally composed of 2 lenses suitably combined, which together form the *eye-piece*.

It will be readily understood that it is no part of my present object to furnish an elaborate account of the theory of instrumental optics; the remarks which follow must therefore be understood to have reference merely to a few general propositions, with which every amateur astronomer ought to be acquainted.

Spherical aberration arises from the circumstance that there are no curvatures practically attainable for a lens such that *all* the rays of light coming from a distant point can be *exactly* united in a common focus.

Chromatic aberration depends on the unequal refrangibility of the different coloured rays which together make white light—so that when an observer views an object through a lens he will not see the image perfectly defined and colourless, but more or less fringed with colour.

In order to lessen as far as possible this latter annoyance, the telescope-makers of by-gone days constructed lenses of great focal length (some of them had foci as long as 300 feet); by this means the chromatic dispersion was diminished in comparison with the size of the image formed. Dollond, from an examination of the different kinds of glass then in use, found that some specimens, under a given mean refraction, dispersed colours much more than others; and starting with this as a basis, he elaborated the compound and achromatic object-glass now in use. This invention was made in 1758, and may well be looked upon by Englishmen as a great national triumph; for it is not too much to say that by its means optical science has been revolutionised. An achromatic object-glass is formed of a convex lens of crown-glass of a greenish hue and

cli. p. 681, 1861; by Robinson, in *Phil. Trans.*, vol. clix. p. 127, 1869; by Lassell in *Mem.* R.A.S., vol. xviii. p. 1; H. C. Key, *Month. Not.*, vol. xxiii. p. 199, April 1863.

a concave lens of flint-glass of a yellowish-white hue, placed in contact, the former outermost. By a proper arrangement of their focal lengths (a subject of considerable theoretical and mechanical difficulty) any 2 selected parts of the spectra formed by these lenses can be united, and the chromatic dispersion is thus to a great extent got rid of, without destroying the refractive power of the object-glass. When a ray of light falls upon such a combination it is acted upon by each component: the crown-glass renders it convergent and disperses it; the concave lens neutralises this dispersion, and a colourless image is (or should be) formed at the focus.

To test whether the spherical aberration has been duly corrected proceed as follows:—point the telescope towards a moderately bright star, say one of Mag. 3, and focus the instrument carefully. Then cover the object-glass with a circular piece of cardboard, in the centre of which a circular hole has been cut having a diameter of about half that of the entire cardboard circle. If the telescope is found to be still in focus, the spherical aberration has been duly corrected; but if otherwise the necessary correction has not been duly made. Should the eye-piece require to be *pushed in*, the instrument has been "*over-corrected*:" should it require to be *drawn out*, it has been "*under-corrected*." As a supplementary test, the cardboard cover may be shaped to obstruct the central rays and leave a free passage for the outer rays.

To test whether the chromatic aberration has been duly corrected proceed as follows:—point the telescope towards some bright object, such as the Moon or Jupiter, and focus the instrument carefully. If on *pushing in* the eye-piece a *purple* ring appears round the object examined, whilst on *drawing* it *out* a *green* ring becomes visible, the chromatic aberration has been duly dealt with; for the colours in question are the central ones of the secondary spectrum appearing as and when they should do.

Be it understood that should a given telescope fail to stand these tests, or either of them, none but an optician can apply a satisfactory remedy.

Before purchasing a mounted object-glass it would be well to submit it to various tests. Air bubbles, striæ, sandholes, scratches, and so forth, are of course, *primâ facie*, bad, but as they are not wholly incompatible with satisfactory performances, over-much attention need not be paid to them. The Rev. T. W. Webb writes

as follows:—"The image should be neat and well-defined with the highest power, and should come in and out of focus sharply: that is, become indistinct by a very slight motion on either side of it. A proper test-object must be chosen: the Moon is too easy; Venus too severe, except for first-rate glasses; large stars have too much glare; Jupiter or Saturn are far better; a close double star is best of all for an experienced eye; but for general purposes a moderate-sized star will suffice. Its image in focus, with the highest power, should be a very small disc, almost a point, accurately round; without 'wings,' or rays, or mistiness, or false images, or appendages, except 1 or 2 narrow rings of light, regularly circular and concentric with the image; and in an uniformly dark field a slight displacement of the focus either way should enlarge the disc into a luminous circle. If this circle be irregular in outline, or much better defined on one side of the focus than the other, the telescope may be serviceable but is not of high excellence. The chances are many, however, against any given night being fine enough for such a purpose, and a fair judgment may be made by day from the figures on a watch-face, or a minute white circle on a black ground, placed as far off as is convenient. An achromatic, notwithstanding the derivation of its name, will shew colour under high powers where there is a great contrast of light and darkness. This 'outstanding' or uncorrected colour results from the want of a perfect balance between the optical properties of the 2 kinds of glass of which the object-glass is constructed: it cannot be remedied, but it ought not to be obtrusive. In the best instruments it forms a fringe of violet, purple, or blue, round luminous objects in focus under high powers, especially Venus in a dark sky. A red or yellow border would be bad; but before condemning an instrument from such a cause several eye-pieces should be tried, as the fault might lie there, and be easily and cheaply remedied[d]."

The "wings" spoken of in the above extract arise from the glass not being in every place of uniform refractive power—a defect sometimes partially remediable, but never altogether curable. For obvious reasons smaller telescopes are less liable to have their efficiency impaired by this cause than larger ones; and when, in

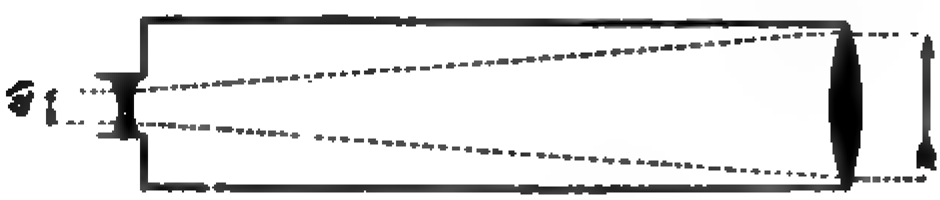
[d] *Celest. Objects*, p. 3. Readers disposed to try their hands at the construction of object-glasses for themselves, will find some useful information in a paper by Webb in the *Engl. Mech.*, vol. xiii. p. 169. May 12, 1871.

using these latter, great precision of definition is particularly desired for any purpose, the defective portion may be covered over by a cardboard screen, and increased sharpness of outline secured at the expense merely of light—an alternative not always beneath notice.

Dawes used to say that the severest test of figure for an achromatic object-glass was the similarity of the image of a bright star viewed with the focus too long to the same image viewed when the focus is to an equal linear extent too short; the amount of the dissimilarity being a measure of the imperfection of the instrument. To this it may be added that in the case of a good telescope the movement of the eye-piece, to the extent of even $\frac{1}{10}$ inch in or out, should seriously derange the sharpness of the image. If it makes but little change the object-glass is not what it ought to be.

If the reader becomes possessed of a refracting telescope, he is strongly recommended never to attempt to take the object-glass to pieces. If the lenses require any adjustment, the maker, or at any

Fig. 211.



THE GALILEAN TELESCOPE.

rate a practical optician, is in every case the best person to take them in hand: unskilful treatment of them may cause much annoyance. It is different with eye-pieces, in consequence of their being less liable to derangement.

Fig. 212.

OPERA-GLASS.

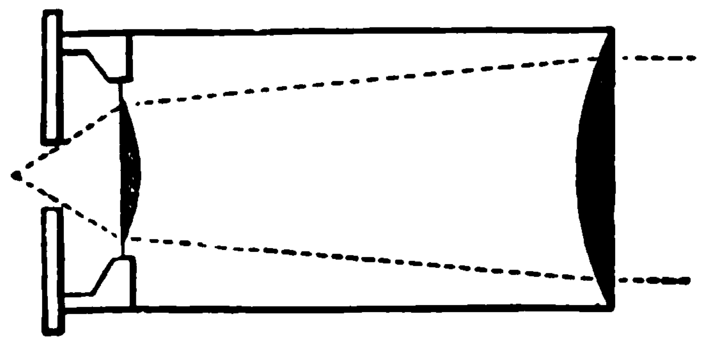
The Galilean refracting telescope, so called from its inventor, the illustrious Florentine, consists of a double *convex* object-glass, the eye-glass being a double *concave* lens placed *in front* of the image formed by the object-glass. The common opera-glass is a telescope on this principle.

The eye-pieces commonly in use are the "positive," or Ramsden's, and the "negative," or Huyghenian, so

called from their having been first used by Ramsden and Huyghens respectively.

A positive eye-piece consists of 2 plano-convex lenses placed with the convex sides towards each other, of which the innermost is called the *field-glass*, and the outermost the *eye-glass*. The focal lengths are equal to each other; and the field-glass should be so far within the focus of the eye-glass, that particles of dust upon the former cannot be seen when looking through the latter.

Fig. 213.



The Positive Eye-Piece.

To find the single lens equivalent to an eye-piece of this description,

Divide the product of the focal lengths of the component lenses by their sum, minus the distance between them [*].

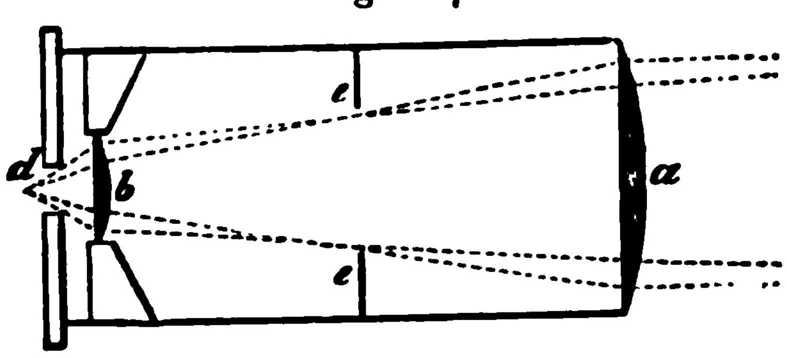
Thus, if the focal length of each lens be 1·5 inch, and the distance between them 1 inch, the length of the equivalent single lens will be—

$$\frac{1\cdot5 \times 1\cdot5}{3 - 1} = \frac{2\cdot25}{2} = 1\cdot125 \text{ inch.}$$

The positive eye-piece having its focus beyond the field-glass, is suited for use with micrometers, and other instruments having wires in the focus of the object-glass—a case to which the negative eye-piece, in consequence of its having, as we shall see, the focus between the glasses, is not suited.

A negative eye-piece consists also of 2 plano-convex lenses, the convex sides of both being in this case turned towards the object-glass. The ratio of the focal lengths of the lenses is usually 3 to 1, the latter representing the eye-glass. In order that the combination may be achromatic, it is indispensable that the distance between the lenses be equal to half the sum of their focal lengths.

Fig. 214.



The Negative Eye-Piece.

In Fig. 214, *a* being the field-glass, a stop, *c c*, to limit the field

[*] A simple method of finding the focal lengths of small convex lenses is given by the Rev. T. W. Webb, in *Month. Not.*, vol. xvii. p. 269. Oct. 1857.

of view is placed in the focus of the eye-glass *b*, and the eye-hole *d* is of such magnitude and distance from the eye-glass that the emergent pencils just find a passage through it. The passage of rays proceeding from an achromatic object-glass is shewn in the figure, where it will be seen that after refraction by the field-glass they come to a focus at *c*, at which place the image of the object is formed. The rays again diverge, and by passing through the eye-glass *b* are in turn converged towards the point *d*, where they enter the eye, and form an inverted image on the retina.

To find the single lens equivalent to an eye-piece of this description,

Divide twice the product of the focal lengths of the component lenses by their sum.

Thus, if the focal length of the field-lens be 3, and of the eye-lens be 1, the length of the equivalent lens will be—

$$\frac{3 \times 1 \times 2}{4} = \frac{6}{4} = 1\tfrac{1}{2}.$$

Negative eye-pieces are almost universally used for all astronomical purposes, except in those cases where they are inadmissible, and which have already been alluded to when speaking of the positive eye-piece.

The following points should be borne in mind—

1. *That in an astronomical refracting telescope the distance between the object-glass and the eye-piece is the sum of their focal lengths, and the magnifying power is the ratio of their focal lengths.*

Thus, let the focal length of the object-glass of a telescope be 10 feet and of its eye-glass $\frac{1}{4}$ inch. Find the magnifying power.

Here 10 ft. = 120 inches.

Then as $\frac{1}{4} : 120 :: 1 : x$.

$: 480.$

2. *That in a Galilean telescope, the distance between the glasses is the difference of their focal lengths, and the magnifying power is the ratio of their focal lengths.*

Thus, let the focal length of the object-glass of a telescope be 6 inches, and of its eye-glass $\frac{3}{4}$ inch. Find the magnifying power.

As $\frac{3}{4} : 6 :: 1 : x$.

$: 8.$

An eye-piece, called Kellner's from the name of its inventor,

Kellner, an optician who lived many years ago at Wetzlar near Frankfurt, is much approved of by some observers, as offering a larger field than a Huyghenian of equivalent power, and with equally good definition. It consists of 2 lenses, the innermost, or field-glass, being a double convex crossed one—that is, having surfaces of different radii, the most convex towards the object-glass; and the outermost, or eye-lens, a meniscus of great convexity and small concavity.

Some observers[f] are warm admirers of an invention known as the "Barlow lens," and indeed it must be admitted that a "Barlow lens" is often found to be a useful accessory to a telescope. The Barlow lens (or, as it would more appropriately be called, Barlow's use of a common lens) is a miniature achromatic object-glass with the curves so arranged as to result in the combination having a negative focus: it is in fact a *compound concave* lens. Such a lens introduced into the main tube of a telescope 5 or 6 inches behind the eye-piece will intercept the rays transmitted by the object-glass before they come to a focus. The image is thrown further from the object-glass than it otherwise would be, and it is proportionally enlarged. By varying the situation of the Barlow lens the amount of the enlargement is varied. As usually fitted, the Barlow lens adds from 50 to 80 or even 100 per cent. to the effective magnifying power of the eye-pieces used with it. And so its possessor will be enabled to make any eye-piece he possesses do the work of 2 eye-pieces[g].

In practice it is not easy to determine with nicety the focal lengths of small lenses, and a better method of ascertaining the magnifying power of a telescope may be given.

Accurately focus the telescope on a distant object, and turn the instrument towards the sky; withdraw the eye backwards a little way and a small luminous circle will be seen upon the eye-glass: this circle is nothing more than the image of the object-glass. Measure by the aid of a fine scale of equal parts the diameter of the object-glass and the diameter of the luminous circle: the ratio will be the magnifying power of the eye-piece used. For example, suppose the diameter of the object-glass

[f] See Smyth, *Cycle*, vol. i. p. 343.
[g] *Phil. Trans.*, vol. cxxiv. p. 205. 1834; *Month. Not.*, vol. x. p. 175. May 1850.

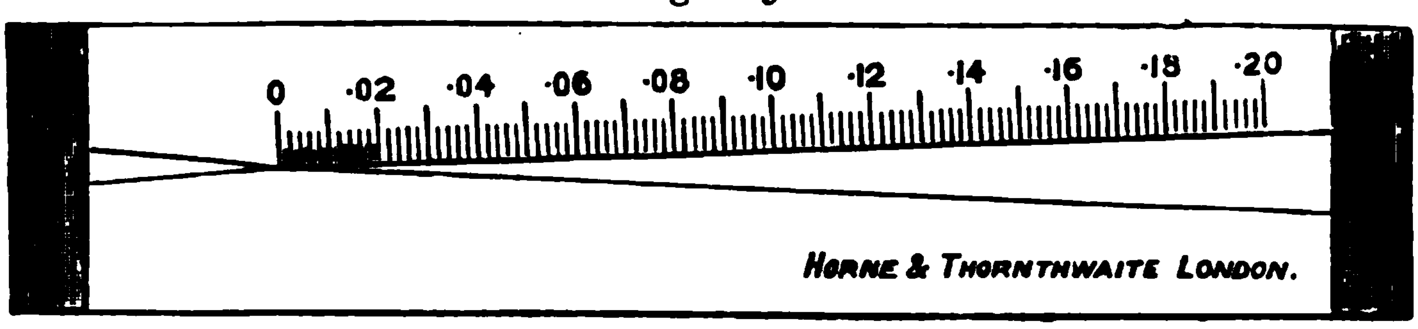
to be 3 in. and the diameter of the circle of light 0·15 in. Then—

$$\frac{3}{0{\cdot}15} = 20;$$

so that the telescope charged with the particular eye-piece used magnifies 20 times. The accuracy of the resulting evaluation will depend on the precision with which the spot in the eye-piece has been measured, and a micrometrical contrivance, called, from its inventor, Ramsden's *Dynamometer*, is in general use for this purpose.

The Rev. E. L. Berthon's Dynamometer, made by Horne and Thornthwaite, is a simple but effective little instrument by the aid of which the magnifying power of any eye-piece can be accurately ascertained. It can also be used to measure the diameter of wire, the thickness of metal, or indeed of any round or flat object, whose diameter or thickness does not exceed $\frac{2}{10}$ inch; and its accuracy is such that its indications are correct to $\frac{1}{1000}$ inch.

Fig. 215.



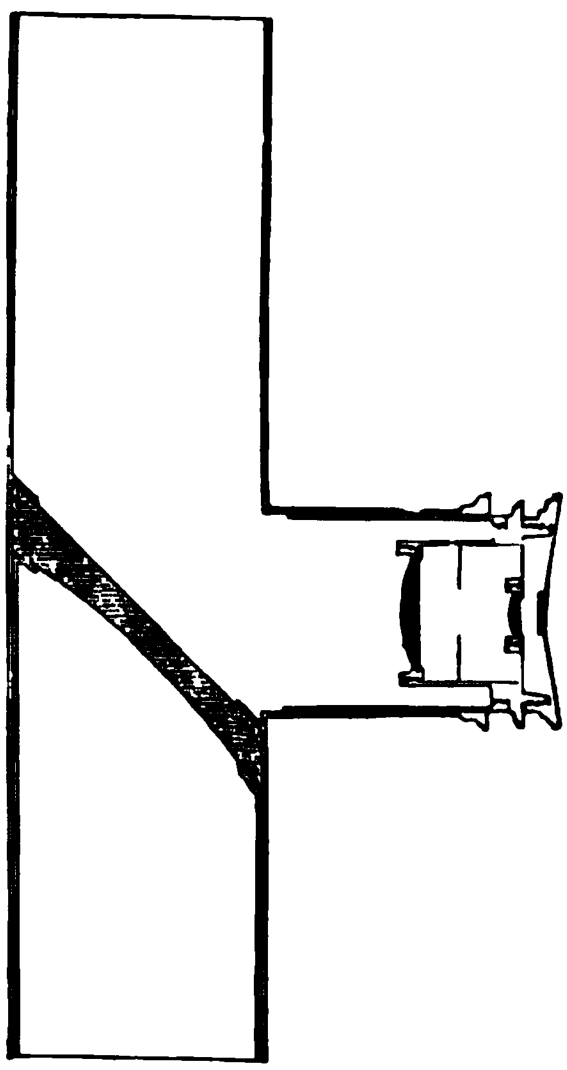
BERTHON'S DYNAMOMETER.

Having placed the eye about 10 inches directly behind the eye-piece, so that the small circle previously alluded to is seen immediately in front of the eye-lens, the process of measuring the image is performed as follows:—Holding the Dynamometer near the eye-piece, observe the miniature disc, by the aid of an ordinary pocket lens, of low power; shifting the Dynamometer until the two internal edges exactly touch the circumference of the image, note the division opposite the point of contact; this is the diameter of the image in decimals of an inch. Dividing now the diameter of the clear aperture of the object-class by this decimal, the quotient is the exact magnifying power of the eye-piece when used with that particular object-glass. Example:—The clear aperture of the object-glass being 6·24 inches, and the diameter of the image, as indicated by the Dynamometer, being ·026, we obtain, by dividing 6·24 by ·026, a quotient of 240, which is the magnifying power.

The diameter of wire, sheet metal, or other object, may be ascertained by sliding it along until the two edges just touch the internal sides of the Dynamometer, when the division exactly opposite the point of contact is equal to the diameter of the article measured. Thus, if a wire passes freely up the wide end of the triangular opening until it is stopped at the first short division beyond ·04, its diameter is ·042 in. The scale is so divided that each long division represents ·01 in. Each of the first two long divisions from O is divided into 10 parts, each of which is equal to ·001 in. Each of the remaining long divisions is divided into five parts, each equal to ·002 in.

In using Berthon's Dynamometer reliance should not be placed on a single result. In every case several distinct observations should be made and the mean taken as the definitive value.

Fig. 216.



The Diagonal Eye-piece.

Dawes contrived an eye-piece for diminishing the apertures of telescopes without disturbing them, which is equivalent to the application of a diaphragm of the required dimensions to the object-glass. It consists of an eye-piece, furnished with a revolving diaphragm, containing apertures of different sizes, each of which can be brought into the centre of the field of view. By sliding one of these apertures towards or away from the object-glass, the cone of rays is respectively reduced or augmented, which has the same effect as diminishing or increasing the aperture of the object-glass. A scale affixed shews the amount of the diminution of the aperture.

It is frequently inconvenient to observe objects near the zenith; to meet this difficulty a diagonal eye-piece is employed. This consists essentially of a tube sliding into the tube of the telescope at the eye-piece end, with another tube let into it at an angle of 45° to the axis. Opposite the secondary tube is a plane reflector which may be either a piece of polished speculum-metal, or a glass (or rock-crystal) prism. The prism is to be preferred,

as much less light is lost in the transmission of the incident rays.

An eye-piece arranged with a single-surface reflection prism is specially serviceable for observing the Sun. It is preferable to view this luminary by reflection and with such a form of prism, for several reasons: amongst others, the loss of light (about $\frac{1}{30}$ only is reflected) is an advantage, and by using a prism there is no second surface to yield a double reflection; and the rays of heat, which are always very inconvenient, almost entirely pass away into the air without traversing the magnifier, and endangering the glasses and the observer's eye. With apertures greater than 2 inches, direct vision of the Sun becomes very hazardous.

A special eye-piece for the Sun was devised by Dawes[h], and works well, but is rather expensive. It consists of a circular metallic plate, faced on the inner side with ivory, and containing a series of apertures of various sizes from $\frac{1}{180}$ to $\frac{1}{2}$ inch; this plate is mounted on an axis in such a way that the holes may be brought in succession into the focus of the object-glass. The apertures serve to limit the field to very small dimensions *ad libitum*, and the field so curtailed is examined by single lenses mounted on another plate revolving concentrically with the former one. Superposed upon the wheel of single lenses is another wheel, containing a series of dark glasses of various shades, to suit the eye and magnifying power used. The single lenses are focussed on the apertures in the diaphragm by a rack and pinion movement, and this renders the eye-piece as a whole complicated and expensive, though it is admirably adapted for solar observation. The wheel of dark glasses is made to slip off the eye-piece, so that if required it can be devoted to other uses.

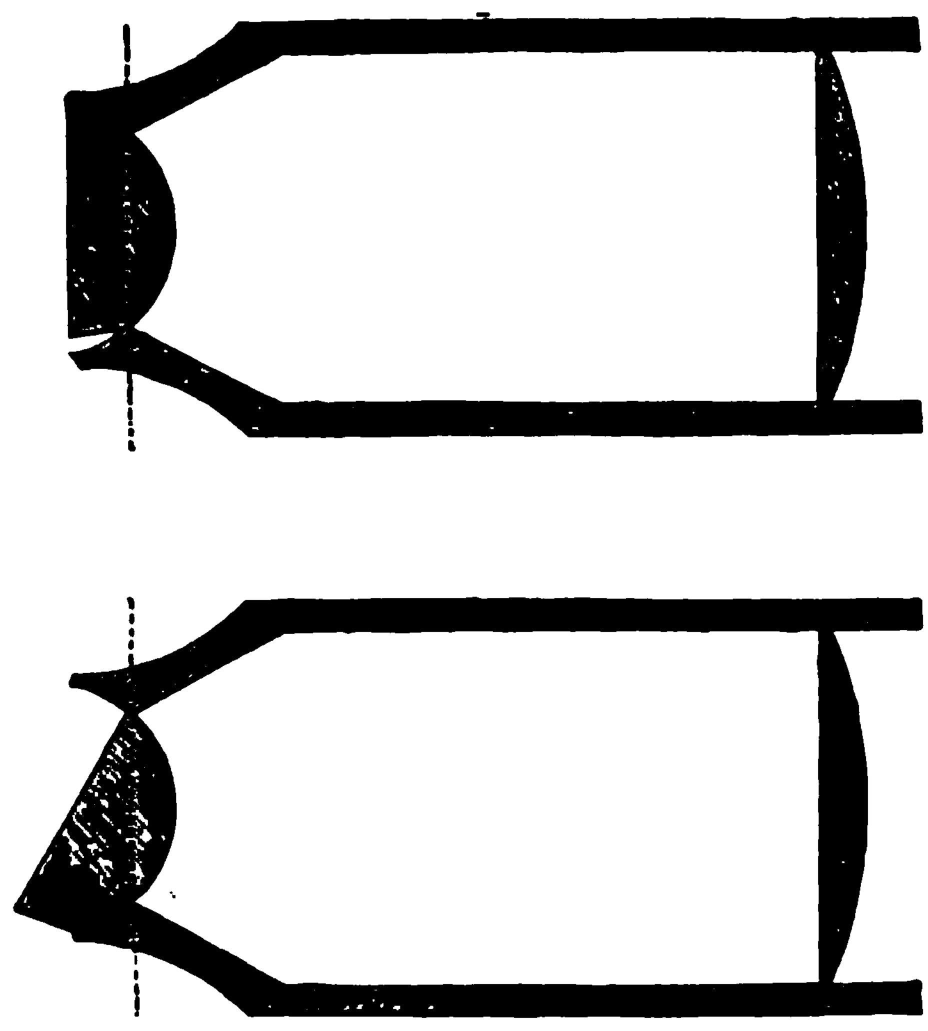
A more simple form of solar eye-piece is that which consists of an adapter in which a diaphragm plate is fitted as above. The wheel of lenses is replaced by a tube, into which fit the diminutive positive eye-pieces required for use with a micrometer. Across the top of each eye-piece is a groove with cheeks, to retain in position a wedge of dark glass, capable of a sliding motion in front of the eye lens, for varying the intensity of the shade. The largest hole in the diaphragm-plate should be equal to the

[h] *Month. Not.*, vol. xii. p. 167. April 1852; *Mem. R.A.S.*, vol. xxi. p. 157. 1852.

field of the lowest power, so that the whole apparatus may, if desired, be advantageously used for other than solar purposes. It is a great feature in this construction that the rack and pinion adjustment for focussing is dispensed with. This is possible because all the positive eye-pieces have the same focus.

To meet the inconvenient effects of atmospheric dispersion on the images of celestial objects viewed at small elevations Sir G. B. Airy has contrived a special eye-piece which deserves mention here. It consists essentially of a common Huyghenian eye-piece

Figs. 217, 218.



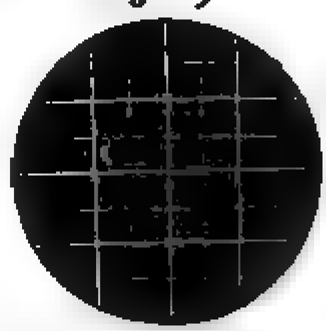
Airy's Prismatic Eye-piece.

of which the eye-glass (supposed to be plano-convex) is made broader than is strictly necessary for telescopic vision, causing it to press by its convex surface into a concave cup at the eye-end of the eye-piece, and allowing it to roll in that concavity, thus presenting different parts of its convex surface, though always in the same form and position, to the rays of light which come from the field-glass, but presenting to the eye a plane surface which in one position of the lens is normal to the axis of the telescope and in another position is inclined thereto. Fig. 217 shews the position of the lens in ordinary use; Fig. 218 shews its position when it is required to neutralise atmospheric dispersion

(or chromatic separation produced by defective centering of the lenses of an object-glass). It will be seen that in each case the dotted line separates a plano-convex lens of definite form; but that in the first case there is, as it were, applied to it on the eye-side, a piece of glass bounded by two parallel surfaces; and in a second case there is applied to it a prism whose angle is varied as the position of the lens in its cup is varied. The eye-piece is provided with a rotatory motion round the axis of the telescope. Such an eye-piece as this presents the following incidental advantages:—it introduces no additional glass; it allows the use of a prism the angle of which can within certain limits be varied at pleasure; and the correction for spherical aberration is not disturbed[i].

Further remarks on eye-pieces will be made in a subsequent chapter devoted to practical hints on observing. It may suffice to add here that a telescope once focussed will generally suit several observers of average sight; for near-sighted persons the eye-piece must be pushed in; for far-sighted persons it must be drawn out.

Fig. 219.



THE RETICULATED MICROMETER.

A micrometer[k] is an appliance used for measuring small celestial distances. The simplest form is that known as the Reticulated[l] Micrometer. It consists of an eye-piece of low power, having stretched across it a number of wires at right angles to and at equal and known distances from each other. All that the observer has to do is to apply the eye-piece to the telescope, illuminate the field with a small lantern (if necessary, as is usually the case at night), and notice how many divisions cover the object whose size it is desired to measure. Knowing the value of each division, the solution then becomes a simple matter of arithmetic. To determine the value of the divisions—accurately focus the telescope on a star at or very near the equator; and note by a sidereal clock the time in seconds occupied by the star in crossing any convenient number of divisions, taking care that the star runs along some one wire. Multiply this by the co-sine of the star's declination, and the product will be the interval in equatorial seconds; this multiplied by 15 will be the

[i] *Month. Not.*, vol. xxx. p. 57. Jan. 1870.

[k] *μικρός small*, and *μέτρον a measure*.

[l] Rete, *a net*, reticulum, *a little net*.

space in seconds of arc. Then divide this by the number of the divisions made use of, and the quotient will be the average arcual value corresponding to each division.

EXAMPLE.

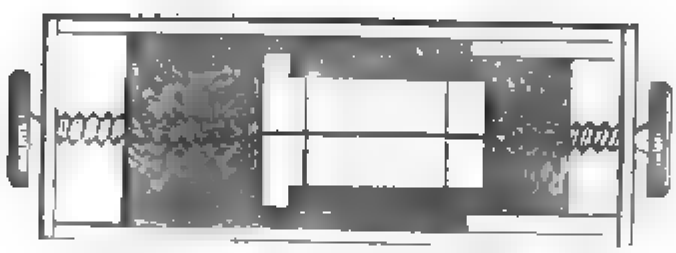
Suppose that β Orionis (Decl. = 8° 21·2′ S) is noted to take 49^s in crossing 4 divisions or squares of the micrometer. Then the calculation will be—

Log. 49	=	1·6901961
Log. cos. 8° 21·2′	=	9·9953680
Log. Interval in Eq. secs. ..	=	1·6855641
Log. 15	=	1·1760913
Log. Interval in secs. of arc ..	=	2·8616554
∴ Interval in secs. of arc	=	727·2″

which divided by the number of spaces traversed, namely 4, gives 181·8″, or 3′ 1·8″ as the value of each. For practical purposes we might consider each of such squares to represent 3′ of arc.

The Reticulated Micrometer is at best but a crude contrivance: the more precise instrument is the *Parallel-wire Micrometer*. This

Fig 220.



THE PARALLEL-WIRE MICROMETER.

in its elementary form may be thus described:—Two spider lines or wires are so mounted parallel on sliding frames that by suitable mechanism of screws &c. they can be made to coincide with each other, or to separate by a small distance. The revolutions of the screws serve to afford a measure of the angular distance travelled over when the angular value corresponding to one revolution is known.

This apparatus is placed in the focus of the object-glass of the telescope so that the eye when it views the object a measurement of which is desired, is enabled (by suitable illumination if necessary, as above) to see the wires clearly. Supposing a comet is visible, and the observer wishes to measure the diameter of its head, all he has to do is to bring the two wires together on one

side of the comet, and then to turn one of the screws until the wire moved is brought to coincide with the other margin of the comet: the number of turns and parts of a turn necessary to effect this is a measure of the angular diameter of the object.

To determine the value of a revolution of the screw—separate the wires by any convenient number of revolutions, and turn the telescope on an equatorial star: note the time in seconds occupied by the star in passing from one wire to the other; multiply this by the co-sine of the star's declination, and the product will be the interval in equatorial seconds. This multiplied by 15 will be the space in seconds of arc. Then divide this by the number of the revolutions of the micrometer-screw, and the quotient will be the arcual value corresponding to each[m].

Another convenient method of determining this value is practised as follows:—Take a foot-rule and place it at right angles to the optical axis of the telescope, at a distance, say, of 100 yards, and observe how many turns and parts of a turn are required to include its length. Ascertain by calculation the angle subtended by the rule, at the distance at which it is placed. Then if a is the angle subtended, and n the number of turns, v, the value of the same, will be represented by the following simple equation—

$$v = \frac{a}{n},$$

which is merely the former rule given in another shape. In the case assumed of the foot-rule, a is $11' \; 27{\cdot}5''$—a fact which it may save trouble to the reader to have stated in this place.

As constructed for use with a large telescope, the parallel-wire micrometer (the above description of which merely takes cognizance of fundamental principles) is a somewhat elaborate piece of apparatus. Spiral springs are inserted, between the frames and the sides of the rectangular metal box which protects the more delicate parts, for the purpose of assisting the screws in their work of driving inwards the frames which carry the wires. On one side of the field of view is a metal comb or notched scale of teeth, which correspond in size to the threads of the screw. Every fifth

[m] The principle of this calculation is identical with that involved in the determination of the value of a square of a reticulated micrometer. I have therefore deemed a separate "example" unnecessary.

notch is cut deeper than the rest, and they are numbered from zero at the centre by tens in each direction. The zero is represented by a small circular hole, and every tenth notch has smaller circular holes drilled under it corresponding in number to the decades of teeth above. The spider lines or wires coincide at zero. The screws have generally about 100 threads to the inch, and near their ends (which are milled-headed) are small circles graduated to 100 equal parts; it follows that the motion of the head through one of these divisions advances the wire through $\frac{1}{1000}$th of an inch. It will be readily understood, therefore, that with a micrometer thus constructed angles of very minute amount may be subjected to measurement[n].

The parallel-wire micrometer mounted so as to rotate at right angles to the optical axis of the telescope, and provided with a third and larger graduated circle concentric with the optical axis, becomes the *Position Micrometer*, which is used for measuring angles made with the meridian by lines joining double stars.

The method of observing such an angle may be thus briefly described. Make the line which is horizontal in Fig. 221 parallel to the equator by shifting it till the larger of the 2 stars passes along it during the whole of its passage across the field; revolve the position-circle through 90°, and the wire in question will then be parallel to the meridian: set the index of the position-circle to zero, bring the larger of the two stars under the wire, and resume the revolution of the circle from left to right, till the wire cuts the other star: read off the position-circle, and the reading will be the angle made with the meridian by the line joining the two stars. Angles of position are measured from the North round by the East, but since eye-pieces invert objects, North becomes South, and therefore the progression is from left to right, or contrary to the motion of the hands of a watch.

The diagram may be taken to represent at one and the same time the graduated circle and the field of view, the latter distinguished into 4 quadrants: north-following, south-following, south-preceding, north-preceding. It should be added that generally 2 wires are used for determining angles of position, the

[n] For an account of a modification of this instrument by Alvan Clark for measuring large arcs, see *Month. Not.*, vol. xix. p. 324. July 1859.

stars being brought carefully between them; by this plan a more accurate result may be obtained than with one wire *covering* the stars.

Of the less common forms the "Double-Image" micrometer and the "Ring" micrometer are the chief.

It frequently happens in using a micrometer provided with wires which have to be illuminated by side-light that much inconvenience arises by reason of the light required for the wires interfering with the visibility of the object when that object is a faint one. To meet this difficulty, Mr. G. P. Bidder has devised a micrometer which, so far as the illumination of the field is concerned, is based on the

Fig. 221.

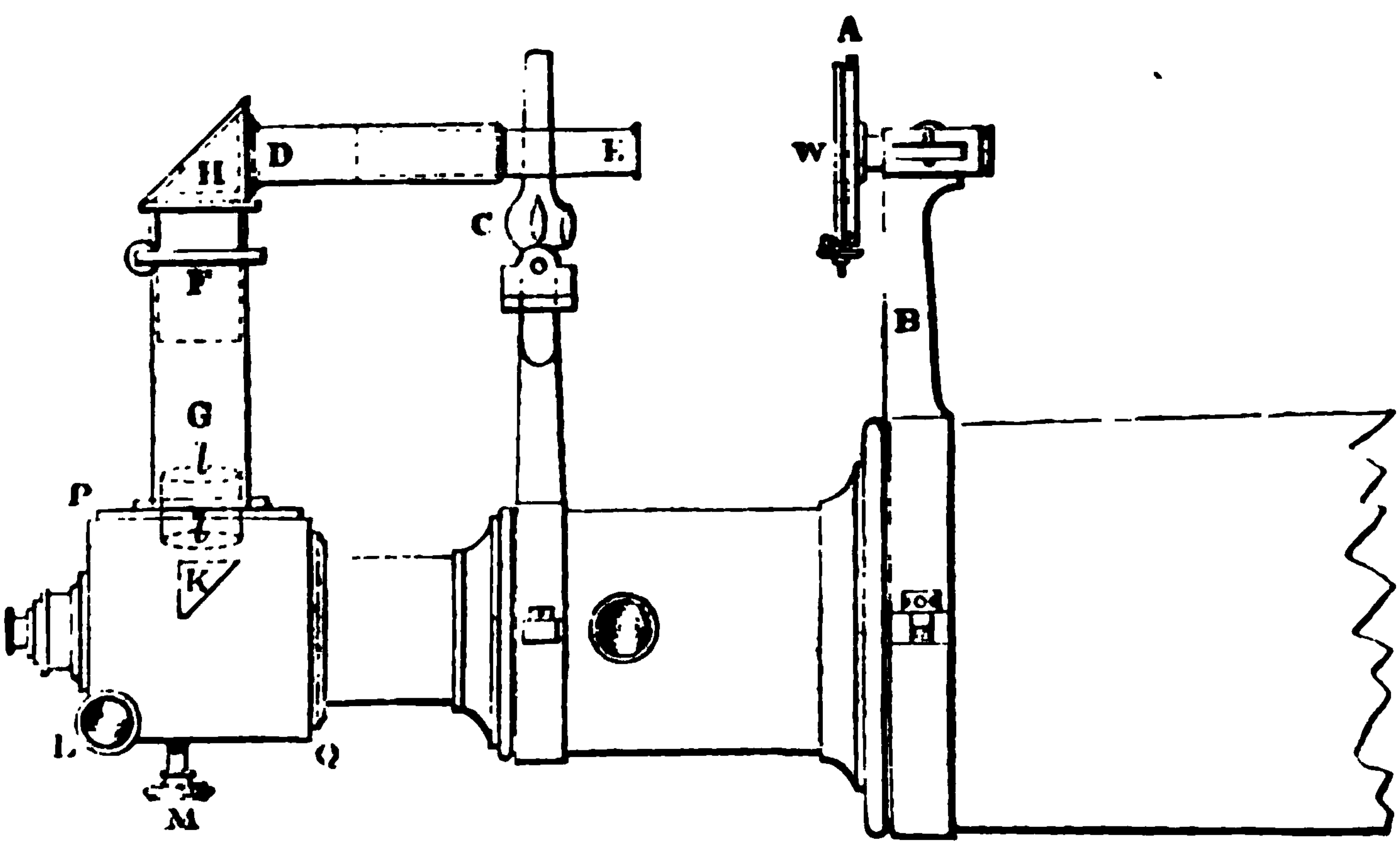
DIAGRAM ILLUSTRATING THE MEASUREMENT OF ANGLES OF POSITION.

reverse arrangement to that usually adopted; that is to say, instead of dark wires on a bright field he obtains bright wires on a dark field. This is brought about in the following manner. The micrometer A, which only differs from the common Position-Micrometer in having no eye-piece in front of the wires, is placed above the telescope on a firm support B. The wires at W are illuminated by a lamp C, in front of them, which is carried on an arm capable of being altered in height and inclination as may be required to throw the light upon the wires. Opposite the wires is a compound tube D E, which is parallel to the telescope and excludes stray light. A dia-

phragm at the end nearest the wires reduces the aperture and assists in the exclusion of stray light. To this tube, but at right-angles to it, is attached, in the way shewn in the diagram, a short tube which slides into a fourth tube F G. This last tube is at right-angles also to the axis of the telescope and is fixed to the square box P Q, which forms a prolongation of the draw-tube of the telescope.

At the intersection of the axes of the tubes D E and F G is placed a rectangular prism H, and within the tube F G a pair of convex achromatic lenses *l l*. Below these, and inside the square box P Q, is a second rectangular prism K, so placed as to be above the cone of rays passing from the object-glass to any point in

Fig. 221.

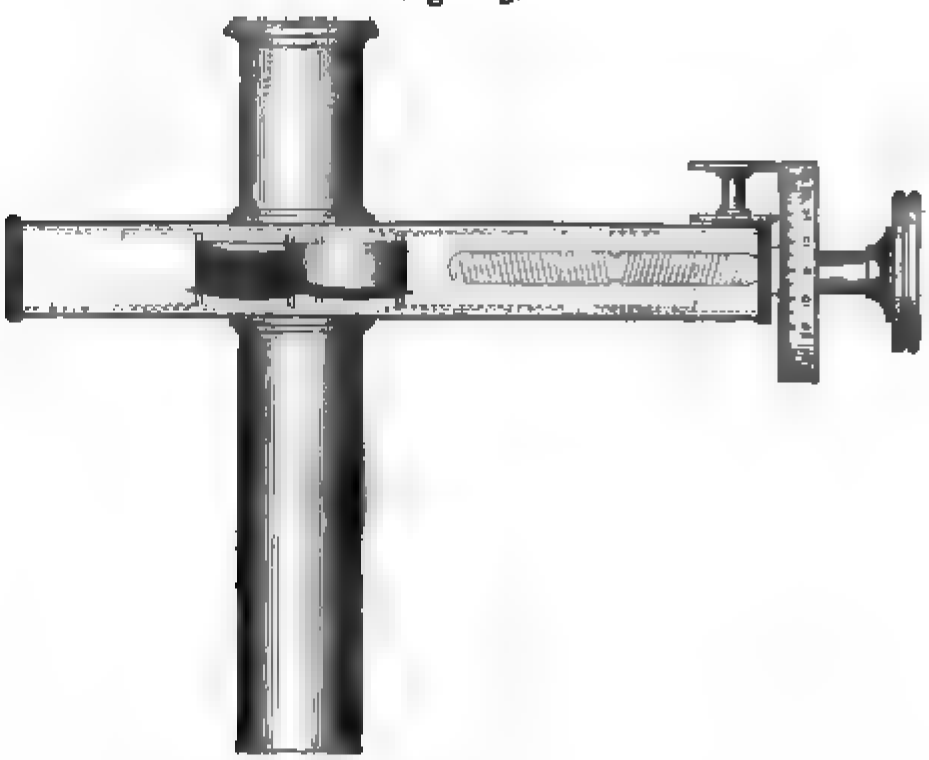


Bidder's Micrometer.

the field. The light from the wires being thrown by reflection at the prism H on to the lenses, these form an image of the wires, which, by adjustment of the position of the lenses, is made, after reflection at the lower prism K, to coincide with the principal focus of the object-glass. The distance from the wires to the lenses being greater than the distance from the lenses to the focus, the image of the wires is proportionally reduced in size and great delicacy of measurement is possible. The wires are seen in the field side by side with the stars to be measured and may be superimposed upon them, but being mere images cannot hide them. The light can of course be reduced until the wires are scarcely

visible. In the case of extremely faint stars resort may be had to an additional expedient. An opaque bar fixed across a short tube is inserted at E in the tube D E, as near as may be to the wires, and so that the bar shall be at right angles to the wires. The effect is to intercept light from a portion of each wire and so produce a dark gap in the image of each. The image of the wires being moved in the field so that the stars to be measured appear in these gaps, they can then readily be measured. The prism K is so mounted that by turning one or both of the screws L M the image of the wires may be brought to any part of the field. It is essential

Fig. 223.



BARLOW-LENS DOUBLE-IMAGE MICROMETER.

to the accuracy of the measurements that the position of the micrometer and of the lenses, and the distance between them, should not be varied when once adjusted. By interposing coloured glass between the lamp and the wires they may be coloured if desired[a].

Fig. 223 represents a simple form of Double-image Micrometer, devised by Browning, which he thinks removes some of the drawbacks which prevent the general use of micrometers based on the principle of double-images. It is formed simply by dividing an ordinary Barlow lens, each of the halves having a separate motion imparted to it by a micrometer screw with two reversed threads

[a] *Month. Not.*, vol. xxxiv. p. 394. June 1874.

cut upon it. The inventor states that he has found the performance of a micrometer thus made to be even more satisfactory than he had anticipated. "It is compact, inexpensive, and possesses the great advantage that it may be used with any eye-piece[p]."

Observers laying themselves out for systematic observations of stars in order to form charts of particular localities will find a "*zone reticle*" of great service. This consists of a thin slip of transparent mica $\frac{1}{1000}$ of an inch or so in thickness, and placed in the focus of the eye-piece of a spider-line micrometer. On this are graduated divisions to represent equal intervals of Declination, with other divisions at right-angles to the former to represent equal intervals of Right Ascension. The mica plate is attached to a diaphragm in the micrometer perpendicular to the axis of the tube and at the common focus of the object-glass and eye-piece. It is illuminated by a cross-light so as to show the divisions as bright lines on a dark field. The transparency of the mica allows the light of stars to mag. 12 inclusive, to be transmitted to a sufficient extent to permit of observations whilst the divisions are illuminated[q].

The Ring micrometer is a German invention[r] and it has not come much into use in England[s].

Other micrometers have been constructed, some optical, some mechanical in their principles, but it does not appear necessary to enter further into the subject than to say that the most important will be found described in the works mentioned in the note[t].

A very useful adjunct to a telescope, especially when it is intended to carry on micrometrical observations, is a *slipping-piece*. This is a framework fitting on one side into the tail-piece of the telescope and fitted on the other to receive the micrometer. With it an observer is able to bring any particular wire to cover any particular part of his field of view without the necessity of moving bodily the whole telescope[u].

[p] *Month. Not.*, vol. xxxii. p. 215. March 1872.

[q] See an engraving and description of such an instrument in *Annals of the Harvard College Observatory*, vol. i. pt. 2. p. 4.

[r] *Ast. Nach.*, No. 28, vol. ii. March 1823.

[s] Loomis, *Pract. Ast.*, p. 115.

[t] *Encycl. Brit.*, Art. *Micrometer*; Pearson, *Pract. Ast.*; Brewster, *Treatise on New Instruments*, 1812; Arago, *Pop. Ast.*, Eng. ed., vol. i. p. 382 *et seq.* See also papers by Dawes in *Month. Not.*, vol. xviii. p. 58, Jan. 1858; vol. xxvii. p. 218, April 1867; *Mem.* R.A.S., vol. xxxv. p. 137. 1867.

[u] See paper by Dawes in *Month. Not.*, vol. xxvii. p. 219. April 1867.

For telescopes up to 5 feet or so in length, the tubes are generally made of brass, but for sizes larger than that, in consequence of the expense of brass, other materials are frequently employed, such as sheet-iron, zinc, or wood. The following is a description of a tube of a very strong and convenient style of manufacture, formed of veneers of mahogany.

"This tube was formed upon a core of dry well-seasoned deal planks, and turned down in the lathe to the following dimensions:—

Length of core	9 ft.	0 in.
Diameter, large end	0	$7\frac{7}{8}$
Do. small end	0	$5\frac{7}{8}$

"The core was well soaped to prevent the possibility of any portion of the glue adhering to it, and thereby rendering the removal of the tube difficult when finished. Upon the core a sheet of thick brown paper was wrapped, its edges being pasted together to serve as a foundation for the first veneer. The core was then brushed over with glue, and a veneer of mahogany then laid round it; a moveable caul made of double canvas was then laid round the veneer, and drawn up tightly by means of screws.

"This caul exactly fitted the taper of the tube, and its longitudinal edges were securely fastened to two strips of wood. In one of these strips, at intervals of about 5 inches, were inserted common bed-screws, moving freely through it, and screwing into corresponding nuts in the other strip. By this means the caul was screwed up tightly round the veneer, thereby ensuring a close contact between it and the core.

"The core was then placed over a stove-pipe, which extended along its whole length, and was slowly turned on its axis until it became sufficiently hot to melt the glue, which thus became equalised, while the superabundant quantity was squeezed out, a portion even permeating the veneer, owing to the pressure of the caul. The core was then set aside for two or three days to dry.

"Every successive veneer, prior to being laid on, was lined with a piece of thin calico, to prevent the veneer from splitting while being turned round the core. This calico was removed when the veneer was dry; after which the surface was prepared for another veneer, by being levelled over and freed from inequalities by the veneer plane. Each veneer was in a single piece, the joints being placed at alternate sides of the tube, and the grain of the wood reversed at every layer. A tube was thus formed of 8 thicknesses, the 7 inner ones being of Spanish mahogany, having stains or other faults which rendered them unfit for *fine* cabinet-work, and therefore of moderate cost (about 9*d*. per foot super). The 8th was of the finest Spanish mahogany, and cost (on account of its great size) about 1*s*. 8*d*. per foot super. The thickness of the tube when finished was $\frac{3}{8}$ of an inch. It was French polished on the outside[1]."

The preceding remarks apply chiefly to refracting telescopes. Reflectors of all sizes save the smallest are usually provided with open tubes, which are hardly tubes at all; rather, tubular frames. This is to secure freedom from currents of air.

[1] F. Brodie, *Month. Not.*, vol. xvii. p. 33. Dec. 1856.

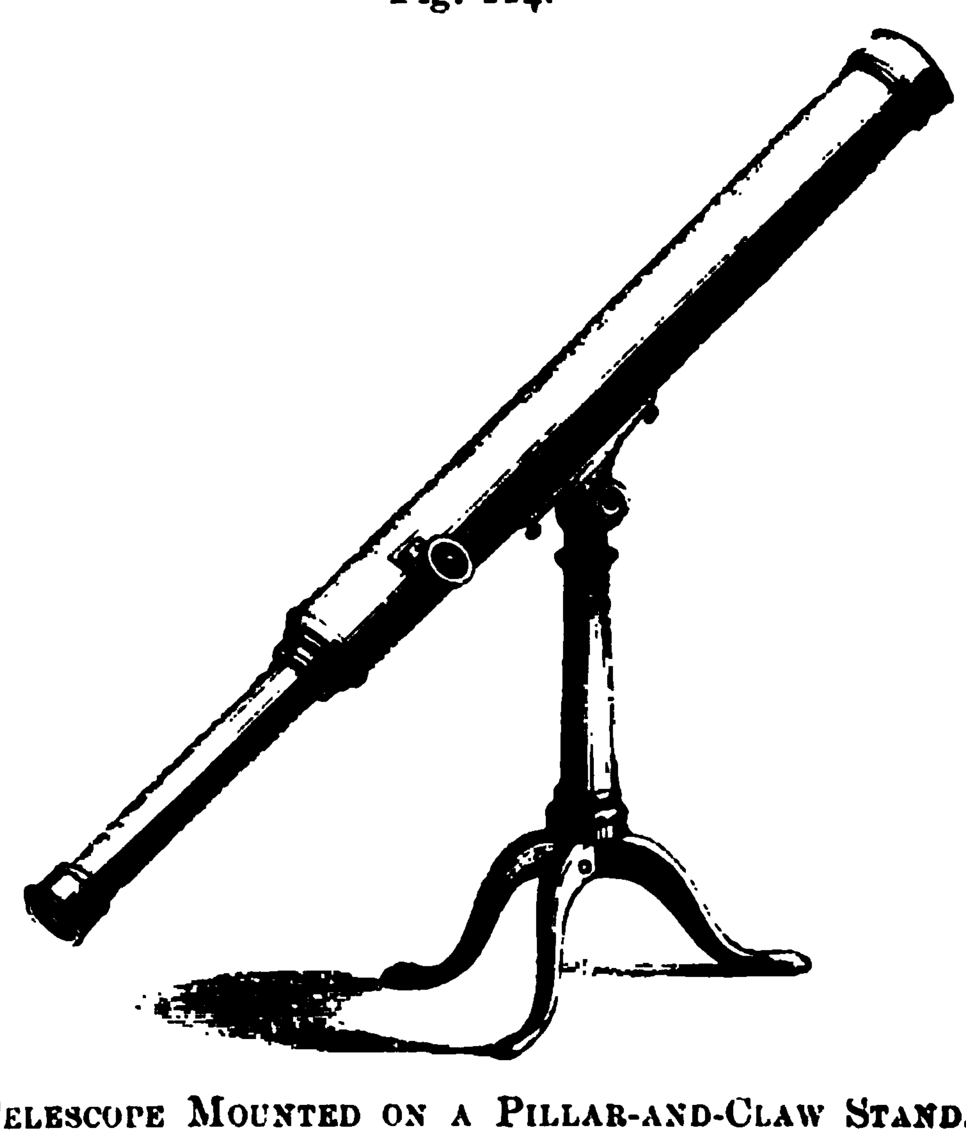
CHAPTER II.

TELESCOPE STANDS.

Importance of having a good Stand.—"Pillar-and-Claw" Stand.—The "Finder."—Vertical and Horizontal Rack Motions.—Steadying Rods.—Cooke's Mounting.—Varley's Stand.—Proctor's Stand.—Altazimuth stands for reflectors.—Brett's Altazimuth mounting for reflectors.

THE manner in which a telescope is mounted is a matter of much more importance than many people imagine. It frequently happens that a good glass is nearly or quite useless because

Fig. 224.



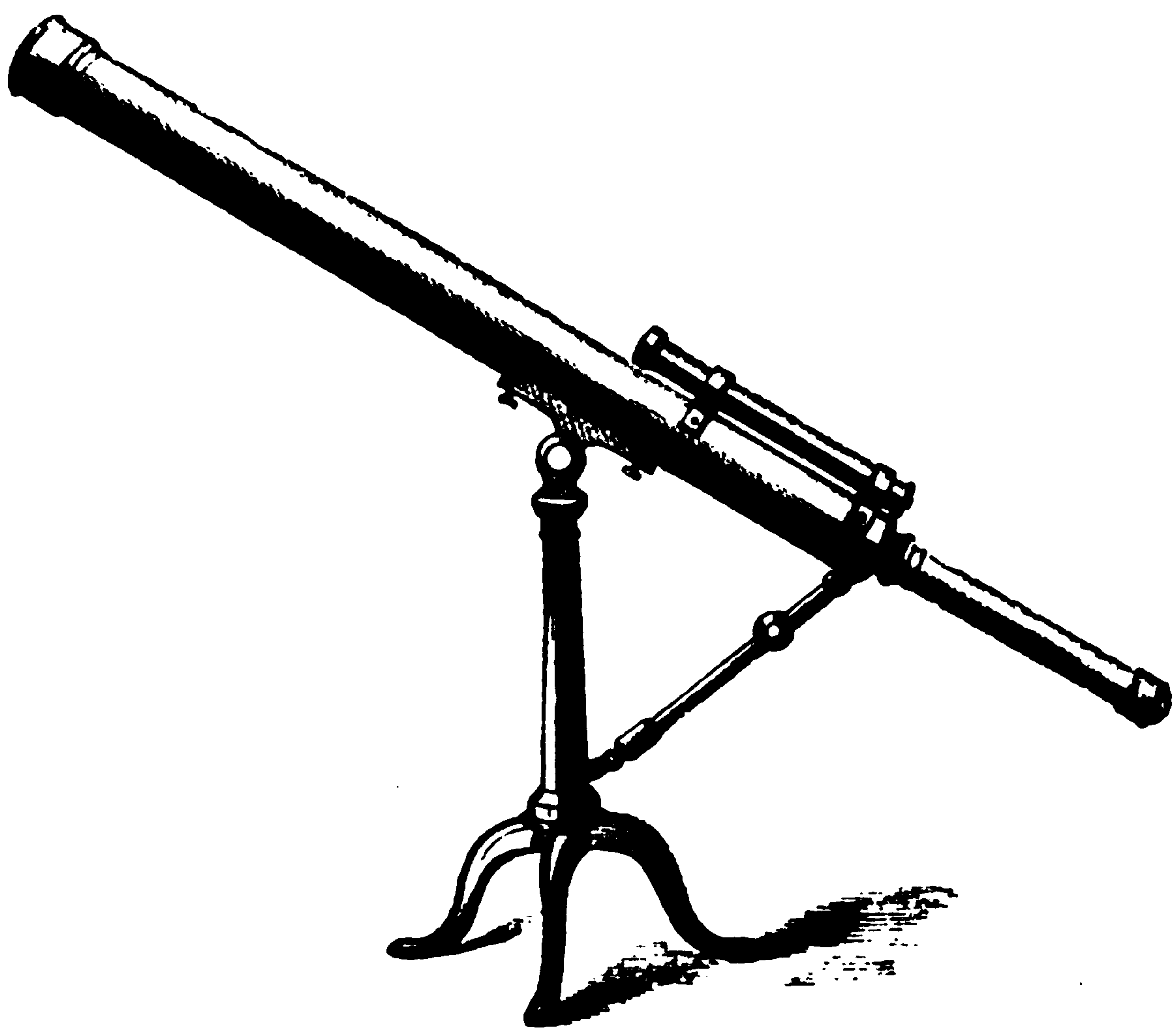
Telescope Mounted on a Pillar-and-Claw Stand.

it is provided with no proper stand on which it may be placed. It is far better for observers who are desirous of deriving some

benefit from the instrument which they purpose to obtain, to get one of smaller size and power, thoroughly well mounted, than to devote their resources to the purchase of some larger glass which is only to be hung up by ropes and spars, under which condition it would fail to possess, in the slightest degree, those most indispensable qualifications, steadiness and facility of movement.

The simplest form of stand is that known as the "pillar-and-claw," and is suited for telescopes of from 24 to 48 inches focal

Fig. 225.



TELESCOPE MOUNTED ON PILLAR-AND-CLAW STAND, WITH FINDER AND VERTICAL RACK MOTION.

length. By its use the observer is enabled to impart to his tube 2 motions, one in altitude, the other in azimuth. The former, or vertical motion, is obtained by a joint at the top of the pillar; the latter, or horizontal motion, by a conical axis carefully fitted into the capital of the pillar by a nut and screw. The telescope is brought to a focus by a rack and pinion. Sometimes, especially in telescopes furnished with a long range of powers, a tube sliding easily within the tube to which the rack and pinion is attached, and called a *tail-piece*, is employed for first getting an approximate focus.

Supposing several powers to be supplied to such an instrument, the observer is recommended to make use of the lowest to find the object he is in quest of: by a little care and practice he will be enabled to change the eye-piece for one of higher power, all the while keeping the object within the field of view.

The first addition to such an instrument as that I have just described, is a "Finder;" which is a small achromatic telescope mounted on the outside of the tube of the large one, the optical axes of both being parallel, and used for the purpose which its name implies. The eye-piece is of very low power, and consequently the field of view is extensive, and being furnished with 2 wires crossing each other at right angles (or better still with 3 crossing so as to leave an equilateral triangle in the centre of the field), it will happen (supposing the wires to be in good adjustment) that when an object is seen at the intersection of the cross wires in the finder (or in the centre of the triangle, as the case may be), it will also be in the centre of the field of the large telescope. Perfect parallelism between the axes of the 2 telescopes is obtained by the use of the screws in the collar which holds the eye-end of the finder, the method of using which will be obvious from inspection.

When it is desired to have greater precision, for the purpose of moving the telescope, than could be given by the hand, vertical and horizontal rack-motions are applied.

The former consists of 2 or 3 tubes which slide one within the other, the largest being attached by a joint to the base of the pillar, and the smallest being secured to the eye-end of the telescope. The 2 larger tubes slide freely, but can be fixed in any position by a clamp; the smallest is moveable by a rack and pinion.

In cases where the horizontal rack-motion is applied, the construction of the pillar differs somewhat from that described at the commencement of this chapter. It consists, as in the former case, of an outside and an inside cone; but instead of the telescope being attached to the inside cone, and that dropping into the outside one, the arrangement is reversed, and the telescope is fastened to the outside one, which drops *upon* the inner one. Upon the lower end of this fixed inner cone a ring is made to move stiffly, and in the edge of this ring teeth are cut, into which an endless screw,

attached to the outer cone, works. When therefore the observer wishes to impart a rapid horizontal motion, he has only to apply to the telescope a force sufficient to cause the outside cone, together with the ring, to revolve upon the inside one; but when a slow motion is desired, it suffices that the endless screw be turned, in

Fig. 226.

TELESCOPE MOUNTED ON A PILLAR-AND-CLAW STAND, WITH FINDER, VERTICAL AND HORIZONTAL RACK MOTIONS, AND STEADYING RODS.

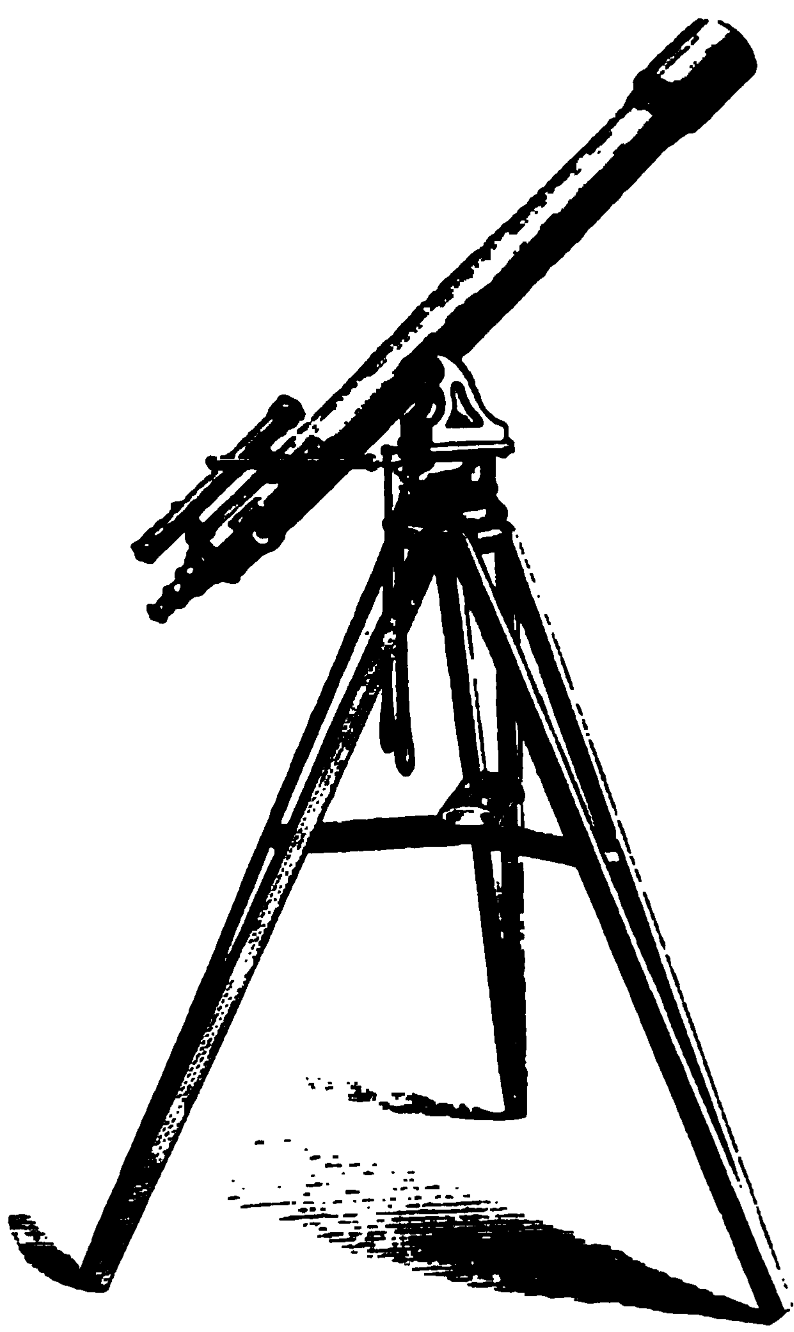
which case the ring, in consequence of the friction, remains attached to the inside and immoveable cone.

Motion may be conveniently imparted in the horizontal direction by attaching to the endless screw a Hooke's joint mounted in a handle.

To all telescopes of a greater length than 3 feet, and which are mounted on a pillar-and-claw stand, steadying rods are a very desirable addition. They are generally 2 in number, and consist of 4 or more tubes sliding one within another, their ends terminating in universal joints fixed to the object-glass end of the telescope and the 2 front "claw-legs" respectively. (Fig. 226.)

Fig. 227 represents a telescope and mounting, by Cooke, of York,

Fig. 227.



Telescope on Stand, with Vertical and Horizontal Rack Motions.

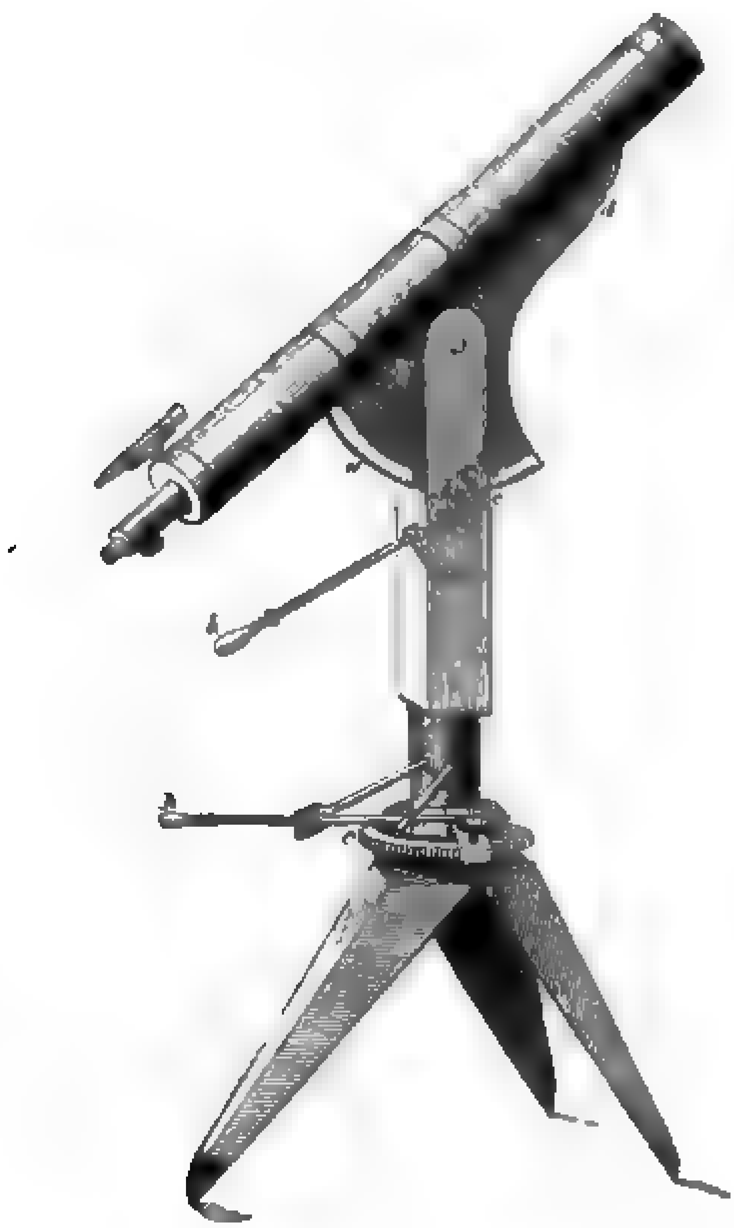
which is extremely well adapted for general purposes, astronomical and terrestrial.

A contrivance known as *Varley's Stand* is sometimes used for telescopes longer than 4 feet; it is a very ungainly affair, and the regular equatorial stand is recommended for instruments too large to be conveniently placed on one of the pillar-and-claw construction: indeed an equatorial may be said to be indispensable for the satisfactory conduct of observations in sidereal astronomy: without

it, much valuable time is apt to be lost in finding the objects sought after, which would be far more profitably spent in scrutinising a larger number found at once by the facilities afforded by graduated circles, &c.

Fig. 228 represents a mounting, having altitude and azimuth motions, devised by R. A. Proctor. The slow movement in altitude

Fig. 228.

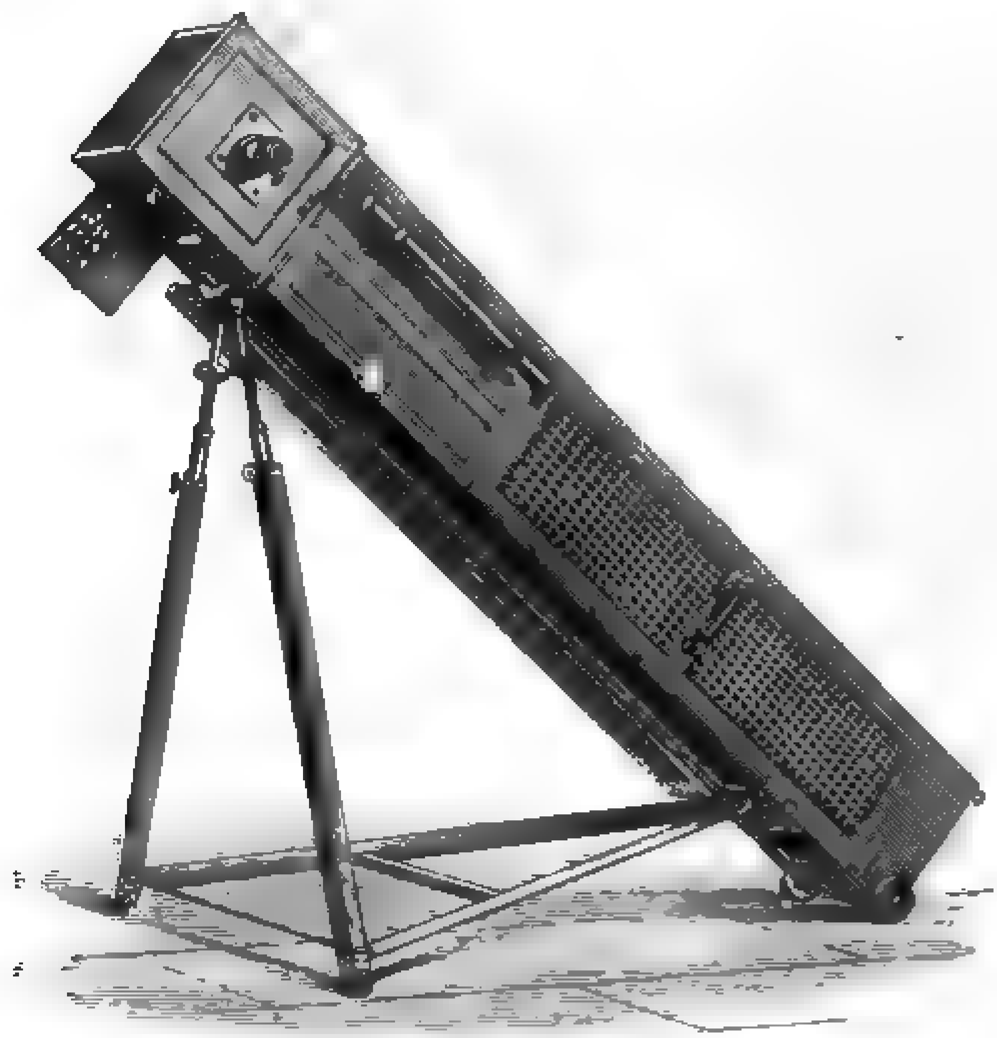


TELESCOPE STAND WITH MOTION IN ALTITUDE AND AZIMUTH.
(*Devised by Proctor.*)

is given by turning the rod *h e*, the endless screw on which turns the small wheel at *b*, whose axle bears a pinion wheel working in the teeth of the quadrant *a*. The slow movement in azimuth is given in like manner by turning the rod *h′ e′*, the lantern wheel at the end of which turns a crown wheel, on whose axle is a pinion

working in the teeth of the circle *c*. The casings at *e* and *e'*, in which the rods *h e* and *h' e'* respectively work, are so fastened by elastic cords that an upward pressure on the handle *h* or a downward pressure on the handle *h'* at once releases the endless screw or the crown wheel respectively, so that the telescope is free to be swept at once through any desired angle either in altitude or azimuth. This method of mounting has another advantage—the handles are conveniently situated and constant in position; and

Fig. 229.



Altazimuth Mounting for Reflectors.
(*Devised by Brett.*)

as they do not work directly on the telescope, they can be turned without setting the tube in vibration[a].

Hitherto in dealing with the subject of stands for telescopes we have been considering exclusively the mounting of Refractors, but Reflectors must not be passed over.

Fig. 229 illustrates a form of altazimuth mounting for Newtonian

[a] *Pop. Sc. Rev.*, vol. v. p. 462. Oct. 1866.

Reflectors which has been devised by J. Brett, and which presents some convenient peculiarities. The telescope is supported at both ends. The pivot on which it revolves is placed at the lower end, and the power by which it is moved is applied as far as possible from the pivot, that is to say at the eye-end. This disposition tends to reduce to a minimum all vibration due to the wind or to any accidental cause. The whole instrument, treated as one piece of apparatus, may be described as a tripod with a moveable apex: and the main peculiarity consists in the means by which motion is imparted to the apex, whereby different parts of the sky can be scanned in succession. The tube itself of the telescope forms one leg of the tripod, the other two legs being each attached to the tube at the eye-end. As the telescope has a given length which is invariable, it is obvious that it may be made to stand at any angle to the horizon by lengthening or shortening the other two legs. Further it is evident that if these two contractile legs be lengthened or shortened equally, the third leg (the telescope) will be moved in altitude only; that if merely one of them be lengthened or shortened the telescope will describe an arc of a circle; finally, that if one leg be lengthened and the other shortened at the same rate, a lateral movement will be communicated to the apex: in other words the telescope will move in azimuth only. Provision may be made for quick and slow motion both in altitude and in azimuth; besides which there may be a slow motion in a circular direction, which motion may be made equatorial by placing the speculum end or pivot of the telescope on some support as many degrees higher (in altitude) than the casters of the other two legs, as shall equal the latitude. The foregoing description aided by the engraving will enable the reader to comprehend generally Mr. Brett's design: for further details his paper must be consulted [b].

In Fig. 230 we have the simplest form of altazimuth mounting for a Newtonian Reflector, which may be said to be the only form of construction in use now-a-days for astronomical purposes. Gregorian and Cassegrainian Reflectors may, it is obvious, be regarded, so far as their mounting is concerned, as if they were Refractors. An instrument such as that now before us should, if well made, be self-balancing in any position, but 4 or at most 5 inches should be the

[b] *Month. Not.*, vol. xxxii. p. 294. June 1872.

diameter of the speculum mounted in this particular and very simple fashion, which is only adapted for instruments intended for use on a table for instance or on some extemporised stand at a window.

The first advance on the form of instrument just described is represented in Fig. 231. Here we have a stand with feet to rest upon the ground; motion in azimuth, convertible into equatorial

Fig. 230.

Altazimuth Mounting for a small Reflector.

motion by tilting the instrument bodily on one side by the aid of suitable adjusting screws; and a slow movement by means of an endless driving screw, with which a handle is connected by the intervention of a Hooke's joint.

Larger and heavier forms of altazimuth are represented in Figs. 232 and 233. These are adapted for mirrors of 6 inches

diameter and upwards; at the same time instruments of such dimensions should by preference be furnished with equatorial

Fig. 231.

ADJUSTIBLE ALTAZIMUTH OR EQUATORIAL MOUNTING FOR A MEDIUM-SIZED REFLECTOR.

mountings. Each of these altazimuths has a quick and a fine screw motion alike in altitude and azimuth. A reference to

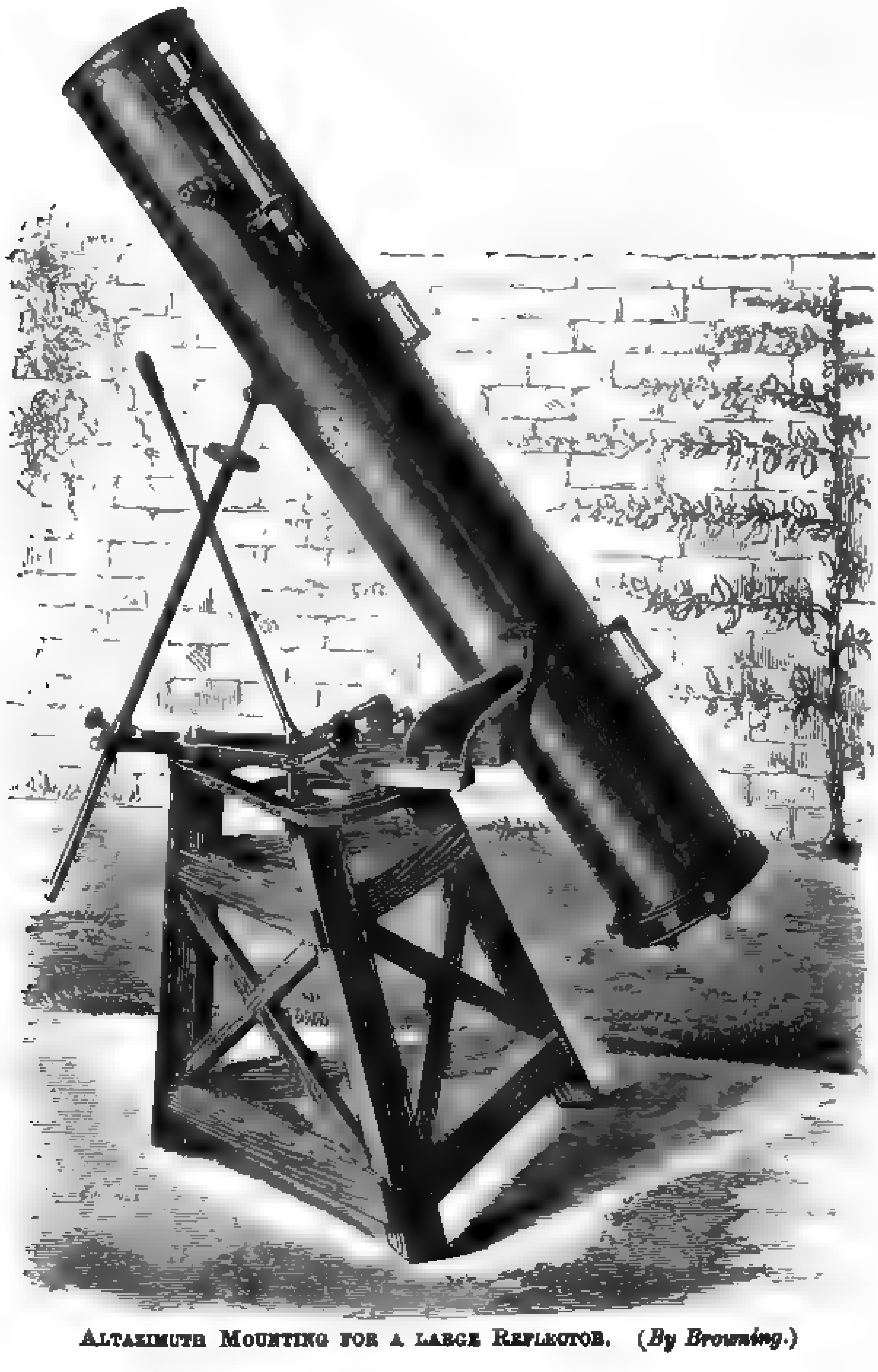
Fig. 232.

Altazimuth Mounting for a large Reflector. (*By Browning.*)

Fig. 233 will enable the reader to see how these motions are obtained. On unclamping the small screw which is visible on

the left of the engraving, and which projects in a nearly horizontal direction, the telescope can be raised or lowered rapidly through an

Fig. 233.



ALTAZIMUTH MOUNTING FOR A LARGE REFLECTOR. (*By Browning.*)

altitude of about 70°. On reclamping the small screw the telescope will become fixed, but a further motion of elevation or depression can be imparted to it, within certain moderate limits, by turning the milled-edge disc which is shown near the top of the altitude-rod and just below the telescope. To move the telescope horizontally to any considerable extent, short of lifting the stand bodily, it is necessary to release a clamping screw which is attached to the tangent screw just above the horizontal arc which forms the top of the stand. On reclamping, a fine horizontal motion can be obtained by turning the tangent screw, to the end of which a long handle for the use of the observer is attached by means of a Hooke's joint. The telescope is equipoised on trunnions, and can be lifted from the stand at pleasure. Occasionally these stands are fitted with a wheel at the foot of one leg, and a handle on each of the other legs, and thus the whole instrument can be moved about like a wheel-barrow.

CHAPTER III.

THE EQUATORIAL.

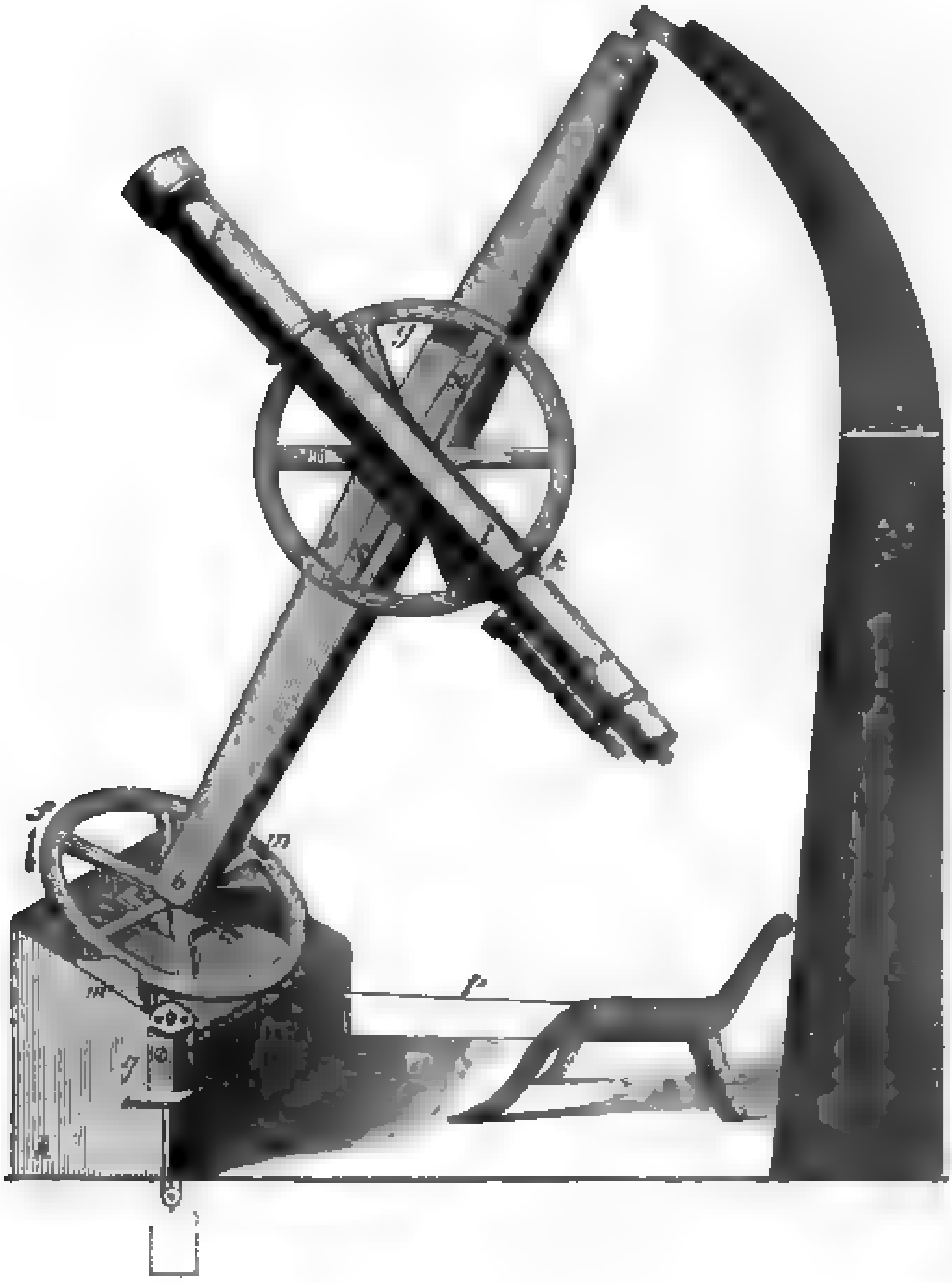
Brief epitome of the facts connected with the apparent rotation of the Celestial Sphere.—Principle of the Equatorial Instrument.—Two forms in general use.—Description of Sisson's form, and of the different accessories to the instrument generally.—Description of Fraunhofer's form of Equatorial.—In what its superiority consists.—The adjustments of the Equatorial six in number.—Method of performing them.—Method of observing with the instrument, reading the Circles, &c.—Examples.—The Star-Finder.—Equatorial mountings for Reflectors.—Universal Equatorial.—Berthon's Equatorial.

THE reader has already been informed that the celestial sphere has an apparent motion of rotation around certain imaginary points in the heavens termed the Poles, only one of which is visible from any given point on the Earth, the equator (in one sense) excepted; that the altitude of the Pole, or angular elevation of it above the horizon, is equal to the latitude of the place of observation; and also that every star describes, apparently, a circular path around the Poles of the heavens, increasing in magnitude with the increase of the angular distance of the star from one Pole up to a distance of 90° or a quadrant, after which it again diminishes towards the opposite Pole.

If now we were to incline the pillar-and-claw stand, already described, in such a manner that the vertical axis should point towards the Pole, and thus be parallel to the axis on which the sphere is supposed to revolve—in point of fact, if we give the pillar an inclination equal to the latitude of our station—it would clearly follow, that a single motion of the telescope, namely one of rotation about that inclined axis, would cause the line of sight (called also the optical axis) to trace upon the sphere a circle cor-

responding to those in which the heavenly bodies appear to move, these circles increasing or diminishing as, by moving the telescope upon the stand or horizontal pivot, we increase or diminish the angle between the line of sight and the first or inclined axis;

Fig. 234.



The English Equatorial.

just as the circles which the heavenly bodies themselves describe increase or diminish according as the polar distance increases or diminishes.

A pillar-and-claw stand placed in the above-described position constitutes a simple equatorial, though in the construction of one

specially designed to serve that purpose numerous alterations of mechanical detail are introduced. Equatorials are all constructed on similar principles, but vary in the manner in which those principles are worked out.

The forms commonly met with are the English or Sisson's, and the German or Fraunhofer's; the latter is for many reasons to be preferred, but the general construction of the former being more readily comprehensible, that will be described first.

Fig. 234 is a representation of an English equatorial; *a b* represents the polar axis; it is directed to the Pole of the heavens, and is supported in this position by the stone piers *h*, *i*, the curved portion of the latter, *i*, being generally made of cast-iron. This axis terminates in cylindrical pivots, which rest in Y's; and one of the Y's, usually the lower one, is provided with means for altering, for the purpose of adjustment, the direction of the polar axis. The declination axis (not shewn, but to which the declination circle, *g*, is attached) passes through the polar axis, and rests upon collars; and, as it is necessary that the two axes should be at right angles to each other, the collar at the end opposite to that at which the telescope is fastened is adjustible by screws. The collar in which the telescope end revolves is held by pivots, which allow a lateral motion through a small arc, in order to prevent any strain being given when the adjustment at the other end is performed. *t t* is the telescope, fixed at right angles to the declination axis, and therefore moving in a plane parallel to the polar axis, great care being taken that the fastenings are perfectly rigid. The eye-end is furnished with means for the adjustment of the line of sight. This is done by means of a transit eye-piece in which a system of cross-wires is arranged, the line of sight passing through the intersection of the middle vertical with the horizontal wire, the whole system being moveable from right to left by screws provided for the purpose.

The angle between the line of sight and the polar axis is measured on the declination circle *g*, divided into degrees and fractions of a degree, and capable of being read off to minutes and seconds by 2 verniers placed at the end of the index plate *x*, and carried round with the telescope. When the line of sight is parallel to the polar axis, and consequently when, if the latter is in adjustment, it points to the Pole, the index arrow on each vernier

should point to 90°, and in order that they may do so, means for adjustment are generally applied to the verniers themselves. A clamp and tangent screw (not shown) near to *k* give the observer the power of fixing the telescope, or of moving it through very small arcs.

The angle through which the plane containing the line of sight and polar axis revolves is measured on the circle *f*, called the hour-circle, which is fixed to the polar axis [a], and divided to shew portions of time—hours, minutes, and, by means of verniers (marked *m*), seconds, the hours being marked from I to XXIV. When the declination axis is horizontal, the zero arrows on the verniers should point to XII and XXIV, facilities for bringing about that coincidence being provided. The hour-circle has a female screw cut on its outer edge, in which an endless screw, which forms part of the clamp at *n*, is arranged to work so as to give a slow motion in Right Ascension, which may either be imparted by the observer himself, through the medium of a rod *p*, terminating in an universal joint, or by means of clockwork at *q*, if a uniform motion is desired for the purpose, for example, of following an object. In order that the 2 actions may subsist independently of each other, it is usual to attach the clock to one end of the tangent screw, and a rod for the use of the observer to the other. The screw is so mounted that when it is required to turn the telescope through a large arc, it can be thrown out of gear.

There are various expedients resorted to in practice, in connexion with the clockwork, and the method of making use of it, &c., which cannot here be specified in detail. Suffice it to say that clockwork is a most necessary adjunct where the telescope is designed for micrometrical and other work which requires both of the observer's hands to be at liberty.

At *e* is the micrometer lamp, the use of which has been pointed out in a previous chapter. A weight is placed at the end of the declination axis opposite to the telescope, to counterbalance the latter; and a spirit level, to set the declination axis horizontal, is also provided, to be used when required.

[a] In some equatorials of the largest class—as, for instance, in the Northumberland, at Cambridge—the hour-circle turns on the lower pivot, and a different method of procedure is adopted.

The German or Fraunhofer's equatorial, so called from its inventor, the optician of Munich, is represented in Fig. 235.

Fig. 235.

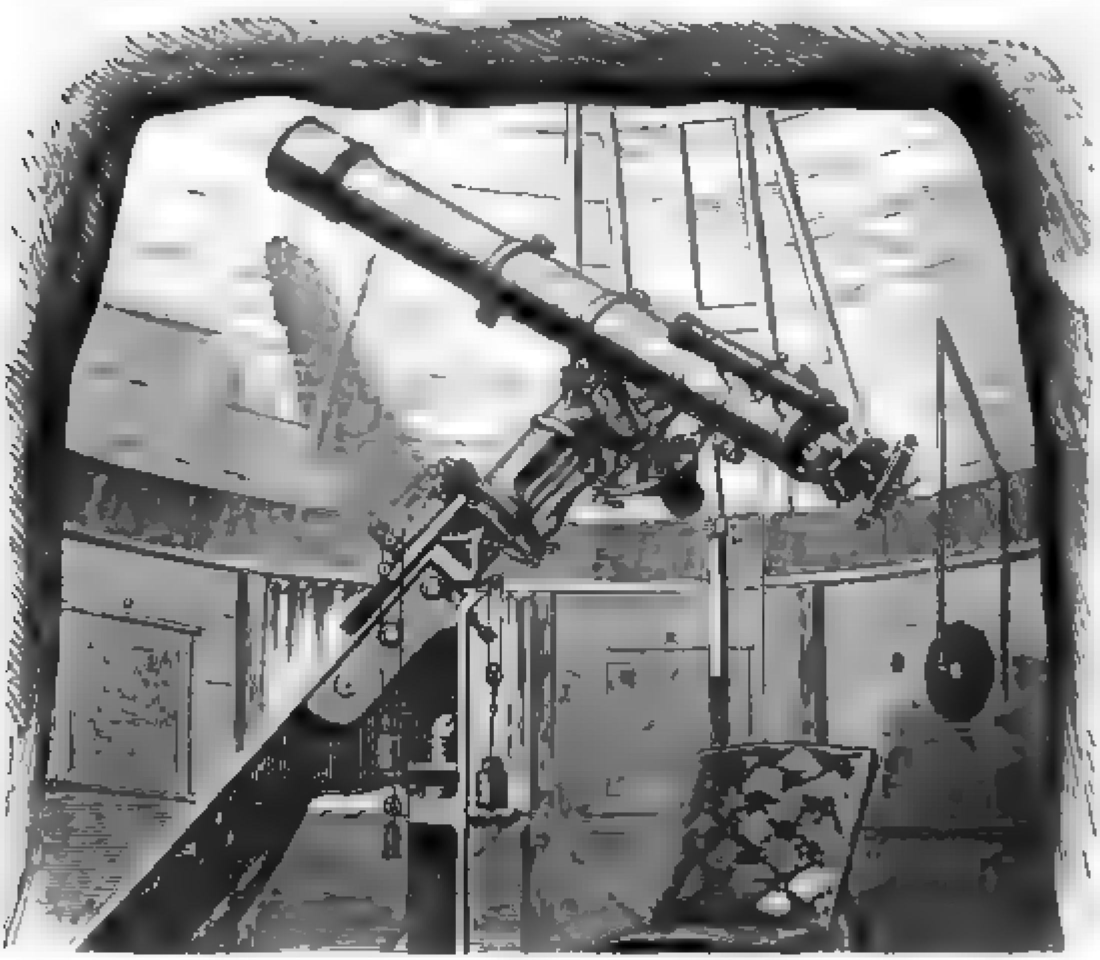
GERMAN EQUATORIAL. (*By Horne and Thornthwaite.*)

There are two principal reasons why this form of mounting is preferable to the one just described:—(1) The telescope will reach every part of the heavens without interruption; whereas it will be

noticed that the upper support required for the polar axis of Sisson's stand necessarily interferes with the view of objects at and below the Pole. (2) This stand requires but one pier easily erected, instead of two, the proper placing of which two, especially in the case of large instruments, occasions much labour and trouble, in order to ensure their being brought within the limits of the adjustments.

Fig. 236 shews a modification of the German form, contrived by

Fig. 236.



Modified German Equatorial.

Brodie. The polar axis is *fixed*, and the telescope is attached to a moveable cradle, which turns on the polar axis. The engraving is from a photograph of an instrument of 7½ inches aperture, formerly erected at East Bourne, in Sussex.

I shall now proceed to describe the adjustments which the equatorial requires. But it should be understood that each one should be performed several times to secure the best possible final results.

They are 6 in number. For correct observation it is necessary—

1. *That the polar axis be placed at the altitude of the Pole.*

2. *That the index of the declination circle point to 0° when the optical axis of the telescope points to the equator.*

3. *That the polar axis be placed in the meridian.*

4. *That the optical axis or line of collimation of the telescope be at right angles to the declination axis.*

5. *That the polar and declination axes be at right-angles to each other.*

6. *That the index of the hour-circle point to 0^h when the telescope is placed in the meridian; that is to say, when the declination axis is horizontal.*

1st adjustment.—*To bring the polar axis to the altitude of the Pole.*

Put on a transit eye-piece, or preferably a parallel-wire micrometer.

Select from the *Nautical Almanac*, or some other catalogue, a star whose position is very accurately known, and which at the time in question happens to be on or very near the meridian. Bring the telescope on to it, and read the declination circle; turn the polar axis half-round and again read the circle; the mean of the two readings is the instrumental declination of the object; correct for refraction, and compare the corrected value with the true declination given in the catalogue. If the selected star be above the Pole and near the zenith, (which it is best that it should be, as chances of error from refraction are reduced to a minimum,) and the instrumental exceeds the true declination, the pole of the instrument is above the pole of the heavens, and *vice versâ*. The polar axis must then be adjusted as needs be, by the screws provided for the purpose.

Example. When ϵ Ursæ Minoris was near the meridian, its declination was observed to be 82° 15′ 20″ when the face of the circle was E., and 82° 15′ 53″ when the face was W.

The mean of these two observations is 82° 15′ 36·5″; the refraction was 52·8″; so that the corrected declination was 82° 16′ 29·3″. The true declination by the Almanac was 82° 17′ 19·3″. Hence the polar axis was too low by 50″.

2nd adjustment.—*To make the index of the declination-circle point to 0° when the optical axis of the telescope points to the equator.*

Take half the difference of the 2 readings obtained as above: this will be the index-error of the declination-circle verniers, and they

must be shifted accordingly by the proper screws. Several pairs of observations should be made, and a mean of them taken to secure an accurate result.

Example. According to the above observation the index-error was 16·5″—additive to readings with the circle E., and subtractive from readings with the circle W.

When the error is small in amount it is often preferable not to attempt to correct it by the screws, but to note the value thereof as a *constant of correction*, to be applied with the proper sign to every observation made.

3rd adjustment.—*To place the polar axis in the meridian.*

Direct the telescope to some known star about 6 hours or so from the meridian on either side, but removed as far as possible from the Pole and the horizon. Read the declination circle: correct for refraction[b], and compare the result with the value assigned in a good catalogue. If the star is E. of the meridian, and its observed declination exceeds that given in the catalogue, the lower end of the polar axis will be to the W. of its true place, and must be moved accordingly. On the other hand, should the observed declination be less than that given in the catalogue, the lower end of the polar axis is too far E., and must be shifted.

Should the star observed be W. of (past) the meridian, the effects of the erroneous position will be reversed, and the adjustments must be reversed also.

Example. The declination of α Ursæ Majoris when 6^h W. of the meridian was observed to be 62° 36′ 11·0″, the face of the circle being W. Correcting this for the index-error found above (16·5″), and for refraction (30·8″), the result was 62° 36′ 23·7″. The declination by the catalogue was 62° 35′ 16·3″. Hence the lower end of the polar axis was 7·4″ E.

4th adjustment.—*To place the optical axis of the telescope at right-angles to the declination axis.*

Put in a transit eye-piece, and observe the time of the passage of some star over the centre wire, and read off the hour-circle. Turn the polar axis half round; observe a second passage, note the time, and again read off the hour-circle. If the interval of time between the two observations corresponds exactly to the difference

[b] A formula for this is given in Loomis's *Pract. Ast.*, p. 29.

between the two readings of the circle, all is right; if not, it is evident that one of the transits has been observed too early and the other too late, on account of the erroneous position of the wires. One half the difference between the interval as measured by the clock and as measured by the hour-circle will be the error of collimation, as it is usually called.

Example. The following observations were made upon δ Ophiuchi:—

Face of Circle.	Sidereal Time. h. m. s.	Hour Circle. h. m. s.
W.	16 12 58·8	0 6 51·0
E.	16 19 9·7	0 13 0·5

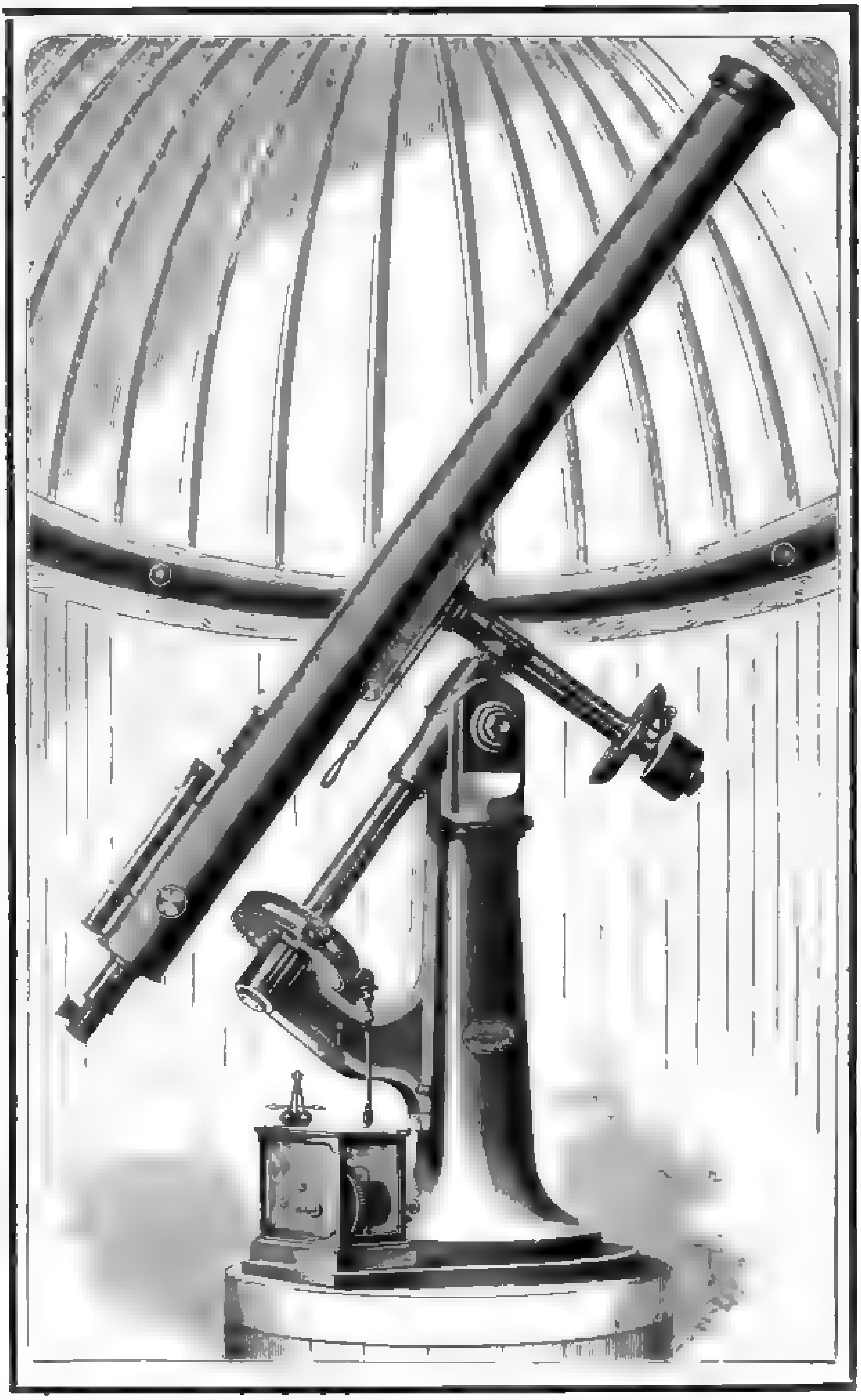
The interval in time was $6^m\ 10{\cdot}9^s$: the difference of the circle readings $6^m\ 9{\cdot}5^s$. The two intervals differed, *inter se*, $1{\cdot}4^s$. One-half of this is $0{\cdot}7^s$, which is the error of collimation, to be added to the readings of the hour-circle when the circle is E., and subtracted when the circle is W. The error may be corrected by the proper screws if the amount is considerable.

It is desirable that the star chosen should be situated as near as possible to the equator, because the apparent angular motion of the sphere is faster at that point than elsewhere.

5^{th} adjustment.—*To set the polar and declination axes at right-angles to each other.*

Place a striding spirit-level upon the cylindrical pivots on which the declination axis turns, and by moving the hour-circle bring the bubble to the middle of its run. The declination axis will then be horizontal[c]. Read the hour-circle; turn the polar axis half round; again bring the declination axis into a horizontal position, and again read the hour-circle. If the readings are the same (or where the circle is graduated to 24^h, differ exactly by 12^h) in both positions, the declination axis is in adjustment. If the readings do not agree, the declination axis is not perpendicular to the polar axis. If the declination axis is furnished with adjusting screws, place the hour-circle half-way between the position which it actually has and that which it ought to have in order that the readings may differ by exactly 12 hours, and make the declination axis horizontal by the screws.

[c] This supposes the level to be itself in adjustment. If not in adjustment, it must be put so before proceeding further. For tests connected with levels see Loomis's *Pract. Ast.*, pp. 46–7.



EQUATORIALLY-MOUNTED REFRACTOR.

Aperture, 4½ inches.

This adjustment ought to be performed by the maker, and when once properly effected is not liable to derangement.

6th adjustment.—*To make the index of the hour-circle point to* 0^h *when the telescope is placed in the meridian; that is to say when the declination axis is horizontal.*

Set the declination axis horizontal by a level; then if the previous adjustments have been duly performed, the instrument will be in the meridian, and the index may be set to zero at once.

A more precise plan is the following: clamp the telescope approximately in the meridian; observe the transit of one or more known stars not far from the equator, and allow for the error of the clock. Then since the R.A. of the star = the true sidereal time of observation $\pm$ the true hour angle from the meridian, the true hour angle is known, and the index may be set to mark it.

It is also requisite that the polar axis should be at right-angles to the plane of the hour-circle. This however need hardly be called an adjustment, as it ought to be attended to by the maker.

It is desirable that all these adjustments should be performed (the second, of course, excepted) with the telescope as near the meridian as possible, this being the most favourable position of the instrument, as ordinarily constructed, for symmetry and strength; moreover, the correction for refraction is applied with greatest facility under these circumstances.

The equatorial being now in adjustment, is ready for use. A few remarks on this subject may not be out of place. Let us suppose that it is required to find a certain star whose R.A. is $16^h\ 40^m$ and declination $+45°\ 47'$, and that the time shewn by the sidereal clock is $12^h\ 16^m$. As the R.A. of the star is greater than the sidereal hour on the meridian, the star sought for has not yet come to the meridian. Subtracting $12^h\ 16^m$ from $16^h\ 40^m$, we have $4^h\ 24^m$ as the East hour angle. Turn the telescope to the East, and set it to the reading, 12^h less $4^h\ 24^m$, or $7^h\ 36^m$ of the hour-circle; then setting the declination circle to $45°\ 47'$ North, the object sought should be seen in the centre of the field. With a little practice in this way the observer will soon be able to fix his telescope upon an object, a small allowance being made to the circle reading for the effect of refraction.

Let us take now the converse of this proposition. Suppose that the observer suddenly picks up an unknown comet, and desires to obtain a record of its place. If he is content with an approximation to the truth, he may proceed thus. Let the comet be placed by the eye in the centre of the field, the time noted, and the circles read off, and the observer will then possess all the required data.

For instance, suppose that at $13^h\ 25^m$ sidereal time a comet is seen in the field of the telescope, the hour angle of which is $4^h\ 17^m$ West, and the declination circle $-\ 9^\circ\ 35'$, what is the comet's position?

Seeing that in this case the object is $4^h\ 17^m$ past the meridian, and that the hour on the meridian ("sidereal time") when the observation was made was $13^h\ 25^m$, it is clear that the R.A. of the comet is $13^h\ 25^m$ less $4^h\ 17^m$, or $9^h\ 8^m$; and the Declination $9^\circ\ 35'$ South.

If the observer is not content with an approximate position, a micrometer must be called into requisition and a *star of comparison* selected. The principle of procedure to be adopted is this: the difference between the Right Ascension and the Declination of the comet and star is ascertained by measurement[d], and the position of the star being known from a standard catalogue, the position of the comet is readily ascertained.

For instance, suppose that the R.A. of a standard star is $16^h\ 16^m\ 35{\cdot}4^s$, and its Declination $+\ 47^\circ\ 15'\ 37''$, and that it is found that a comet precedes the star in question by $2{\cdot}7^s$, and is North of it $4'\ 21''$ in Declination, what is the comet's position?

	R. A.			Decl.
	h. m. s.			° ′ ″
Star	16 16 35·4	..	.. ..	+47 15 37
Subtract ..	2·7	..	Add ..	4 21
True R. A.	16 16 32·7		True Decl.	+47 19 58

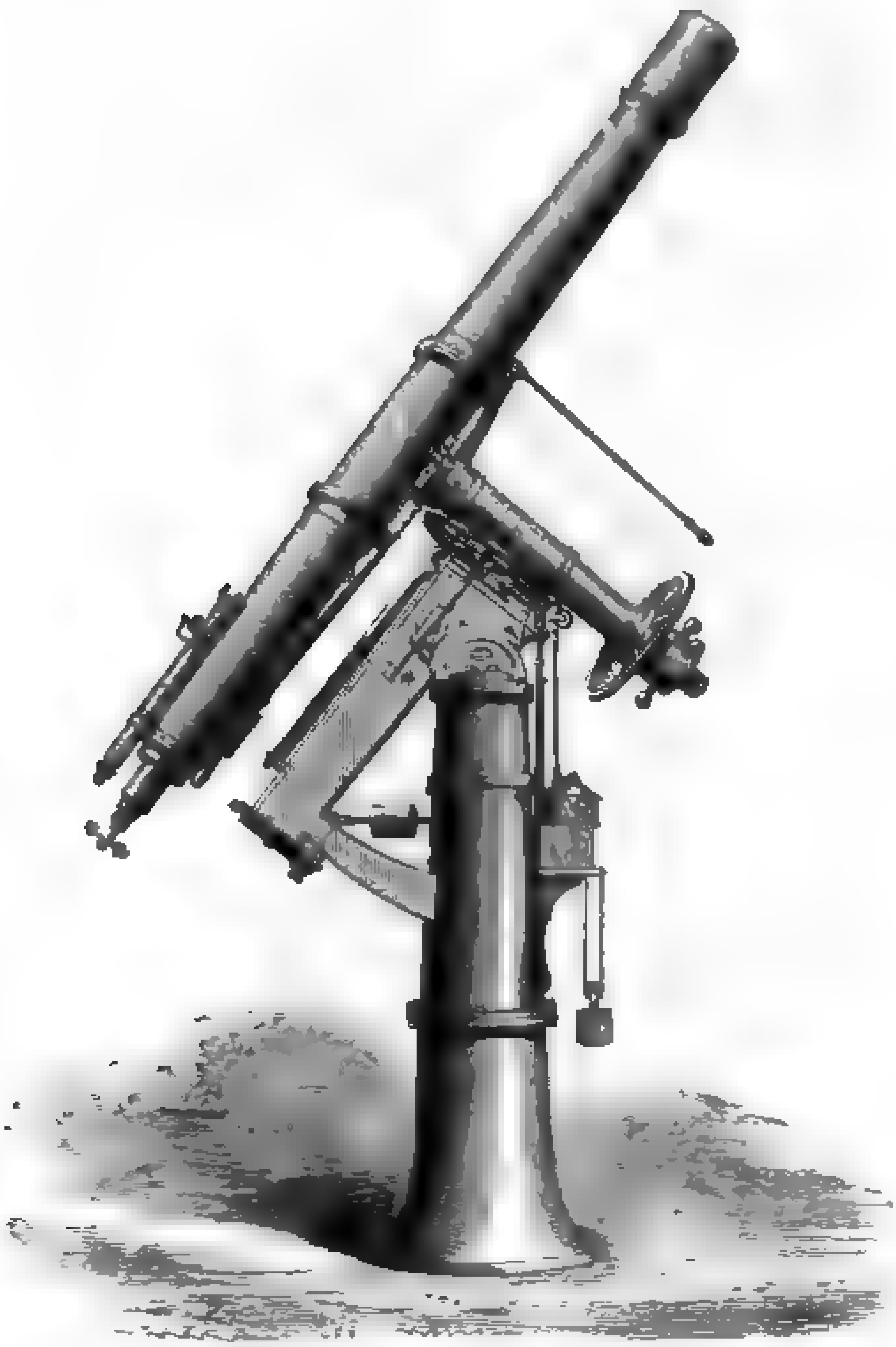
In practice, index errors and correction for refraction must be scrupulously taken into account when precision is required.

An arrangement has recently been introduced which is greatly calculated to facilitate the employment of the equatorial. The graduated hour-circle revolves freely on the polar axis; below it is *fixed* an index, which is (or should be) exactly in the meridian; immediately

[d] Or by clamping the equatorial and noting the interval of time between the transit over the micrometer wire of the comet and star respectively.

above the moveable circle is another circle, fixed to the polar axis, not graduated, but carrying another index which coincides with the lower one when the telescope is in the meridian. To find an object,

Fig. 238.



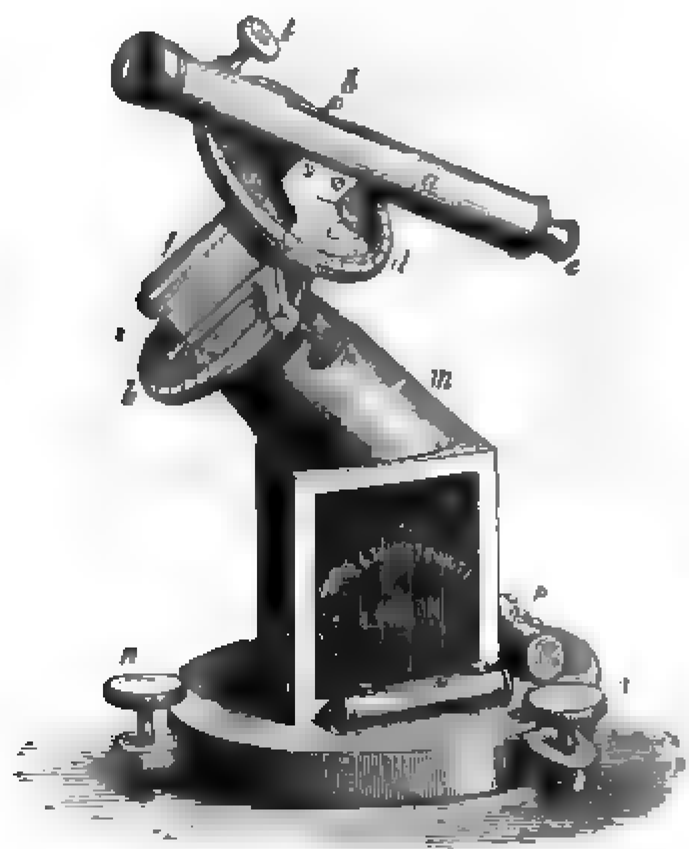
THE EQUATORIAL OF THE UCKFIELD OBSERVATORY. (*By Cooke.*)
Aperture, $8\frac{1}{4}$ in. Focal length, 11 ft. 5 in.

all that the observer has to do is to bring to the fixed index that point on the moveable hour-circle which corresponds to the R.A. of the object sought; to clamp the same, and then to shift the upper

circle till the index which it carries points to the hour on the hour-circle corresponding to the sidereal time shewn by the clock. The telescope being duly set in Declination, the object will be found in the field. The time and trouble saved by this simple expedient can only be fully appreciated by actual experience.

Mention may here be made of a little instrument which, though a German equatorial in its essential features, has points of its own calculated to render it of use to many amateurs, namely Horne and Thornthwaite's *Star-Finder*.

Fig. 239.



The Star-Finder.

The particular idea aimed at in its conception was to furnish the means of either ascertaining the position of any important celestial object, preparatory, it might be, to an examination of it with an efficient but non-equatorially-mounted telescope, or to determine the identity of any object already observed.

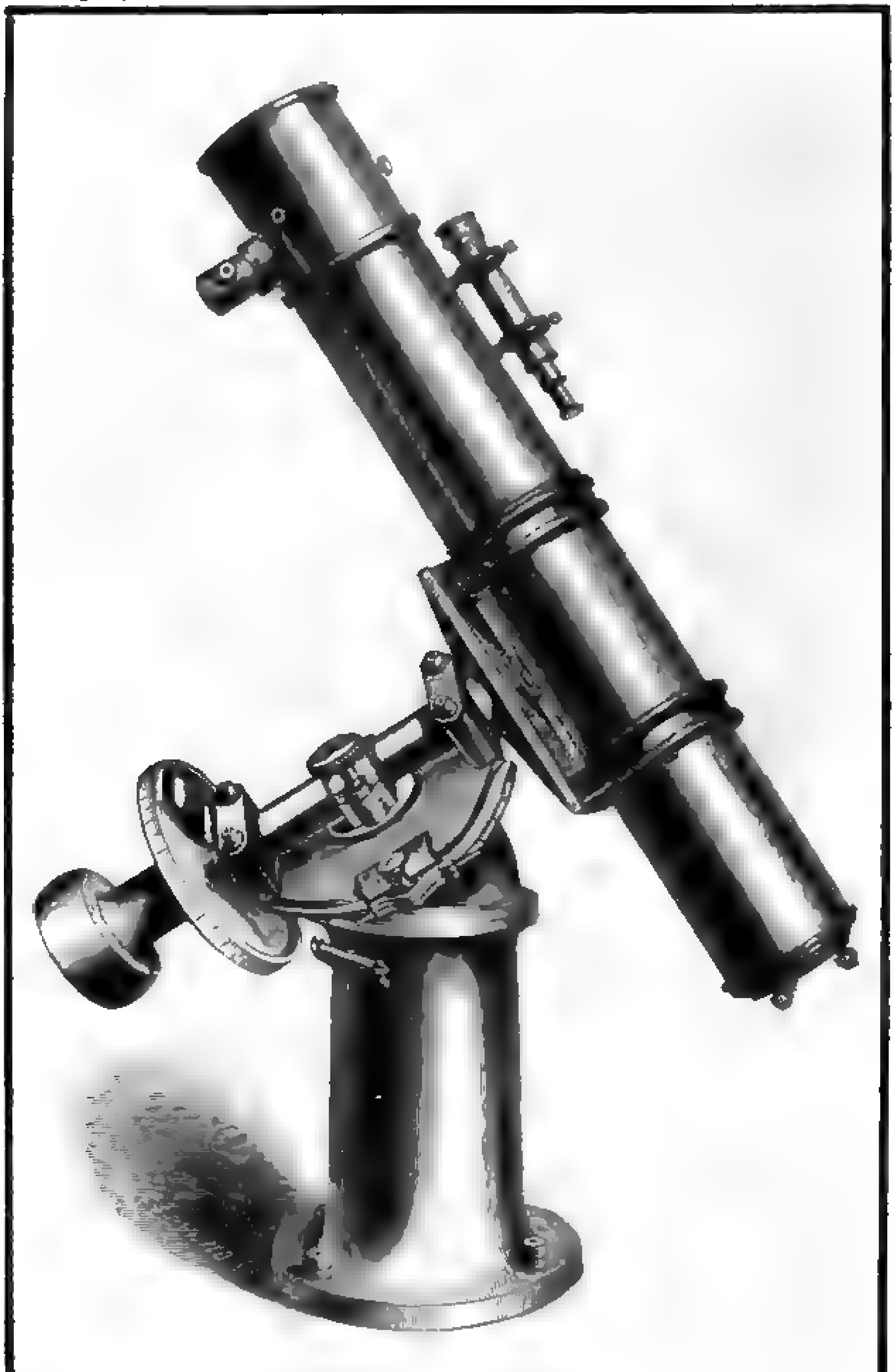
The instrument consists of a telescope *a*, having at *b* a sliding adjustment and at *c* an eye-piece furnished with cross wires. The tube occupies the diameter of a divided circle *d* (which is the declination circle), the graduations of which proceed from 0° at the head and foot of the circle both ways to 90° at the sides,

and which are read off by a vernier index *e* carved upon the flank, as it were, of the telescope *a*. The scales are appropriately lettered N and S respectively upon the left and right halves of the circle. Passing through the centre of the declination circle is the arm *f*, which admits the revolution of the tube, and itself occupies a diameter of the hour-circle *h*. This circle, graduated into 24 hours, and degrees of 4 minutes (of time) each, from zero on the right, is read, by the vernier index *i*, at the extremity of the arm of declination *f*. Clamping-screws, *k* and *l*, secure the telescope and arm of declination to their respective circles. The latter arm, attached at right-angles to a carefully-fitted polar axis, is capable of taking up any position upon the hour-circle *h*, which is equally fitted at right-angles to the polar support *m*. It is necessary that this support be accurately adapted (by an easy adjustment provided by the maker) to the latitude of the place where the star-finder is intended to be employed. It is fixed to a massive iron foot, which must be placed perfectly level by the three foot-screws *n n n*, with observations of the levels *o* and *p*.

To level the bed of the instrument, adjust the milled heads *n n n* until the bubbles of air in the spirit-levels *o* and *p* are exactly in the middles of the tubes, the hour-circle of the instrument facing to the north. Now reverse the instrument, that the hour-circle *h* may face the south. If the bubbles of air in both levels still remain central, the bed or support is truly level. But if the bubbles be not so, the support must be lowered at the sides where the bubbles appear. The bubbles should be only *half* corrected by this depression of the support, the remaining half of the apparent error being due to the foot-screws, which were adjusted at the first observation to meet the errors of the support. A few trials will fix the support quite horizontal; and if it be a stone pier or pillar, the slab which forms its surface may be cemented in this position. The general adjustments are the same as those of the equatorial.

In applying to a reflector an equatorial mounting, though of course the principle remains the same yet the greater dimensions, weight, and, I will add, awkwardness of reflectors (that is to say Newtonians, which virtually are the only ones in use) necessitate the adoption of various practical expedients which will appear strange to persons accustomed only to refractors.

Plates XXX, XXXI, XXXII, represent various equatorial



EQUATORIALLY-MOUNTED REFLECTOR.

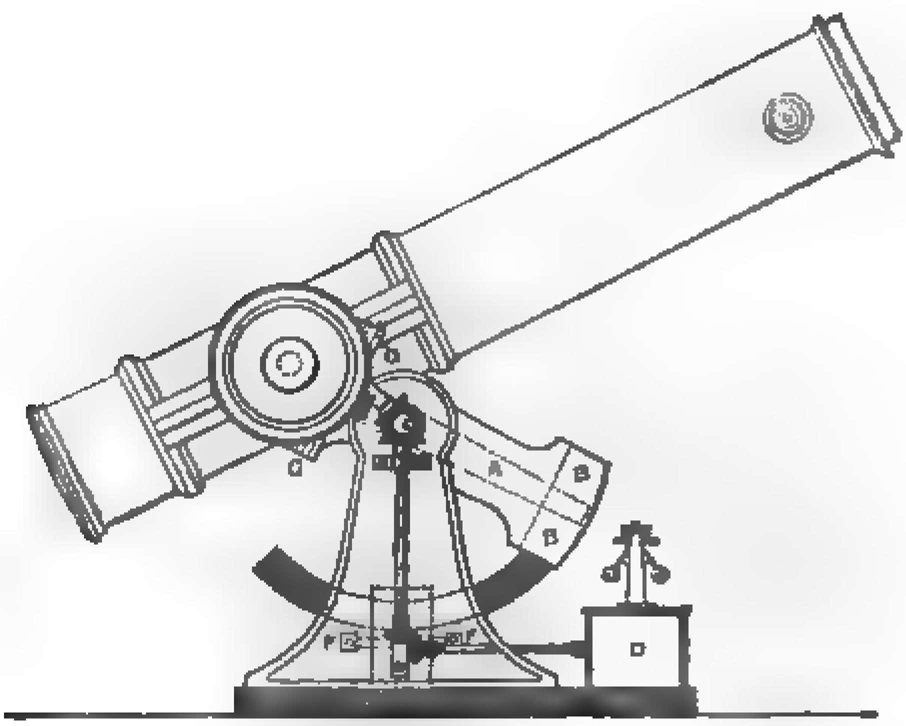
(By Browning.)

Aperture, 6½ in.

mountings for reflectors by Browning of London. The last of these is a large and fine instrument which is now the property of Lord Lindsay and is erected at his observatory at Dun Echt, Aberdeenshire. The general construction of each of these instruments will be sufficiently understood from the engravings, but in the case of the two larger instruments the tubes are so arranged that they will revolve bodily, and thus the respective eye-pieces can be brought at pleasure to the position which will best relieve the observer from straining either his body or his eyes.

Lord Lindsay's equatorial is fitted with clockwork of special construction. The clock is placed on the North side of the

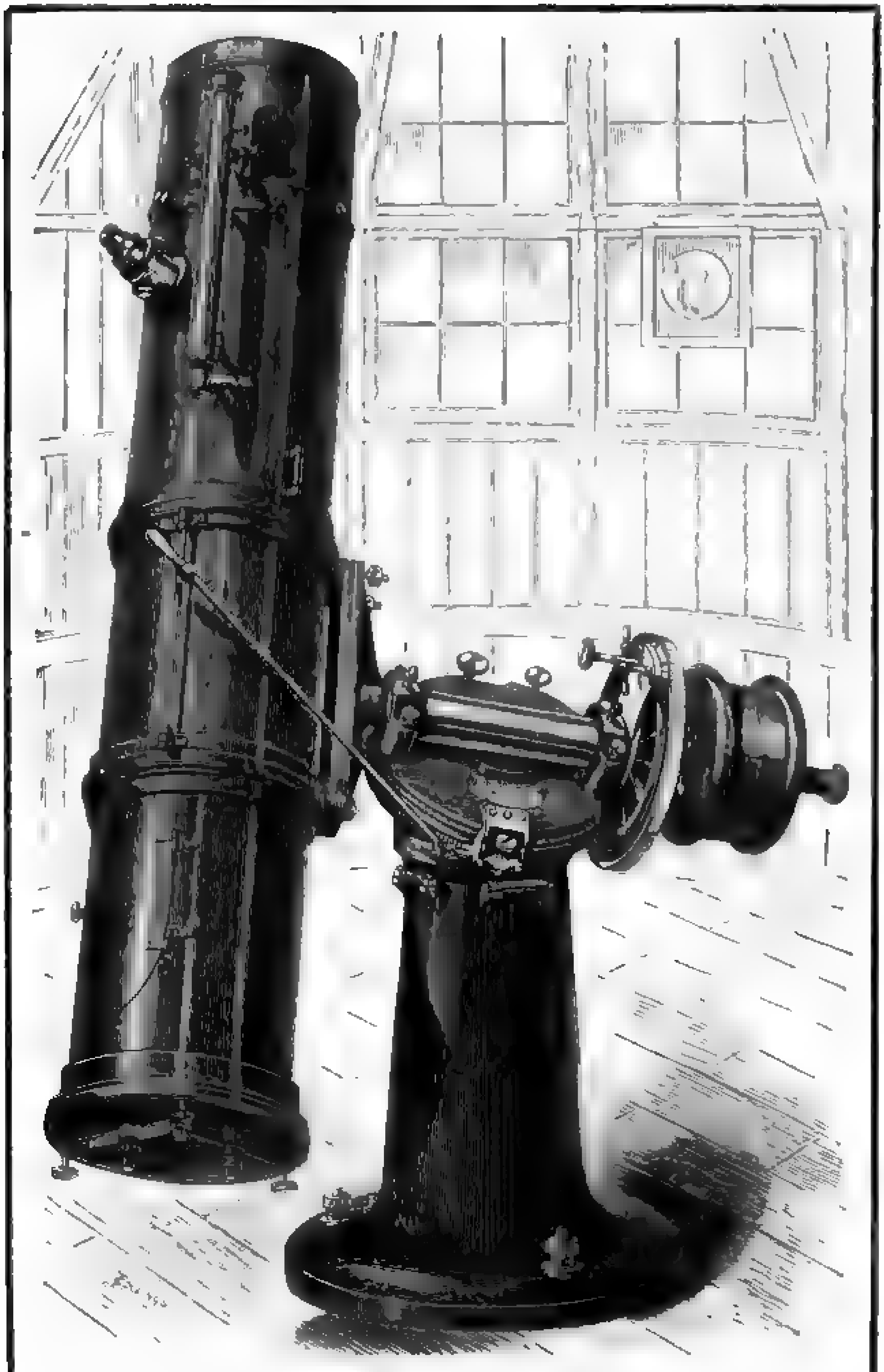
Fig. 241.



UNIVERSAL EQUATORIAL FOR A REFLECTOR.

instrument so that it shall be as much as possible out of the way and protected from injury. Means are provided to enable an observer using the finder to bring an object into the centre of the field of the large mirror.

Fig. 241 represents a form of Universal Equatorial, for a reflector, originally devised by Sir G. B. Airy but perfected as regards mechanical details by Browning. The whole telescope together with the polar axis is carried by centres at E; large plates are attached to the sides of a cradle which carries the polar axis; A is the said axis; B B the cradle; C C an arc provided with a clamping arrangement of which the adjusting screws are shewn

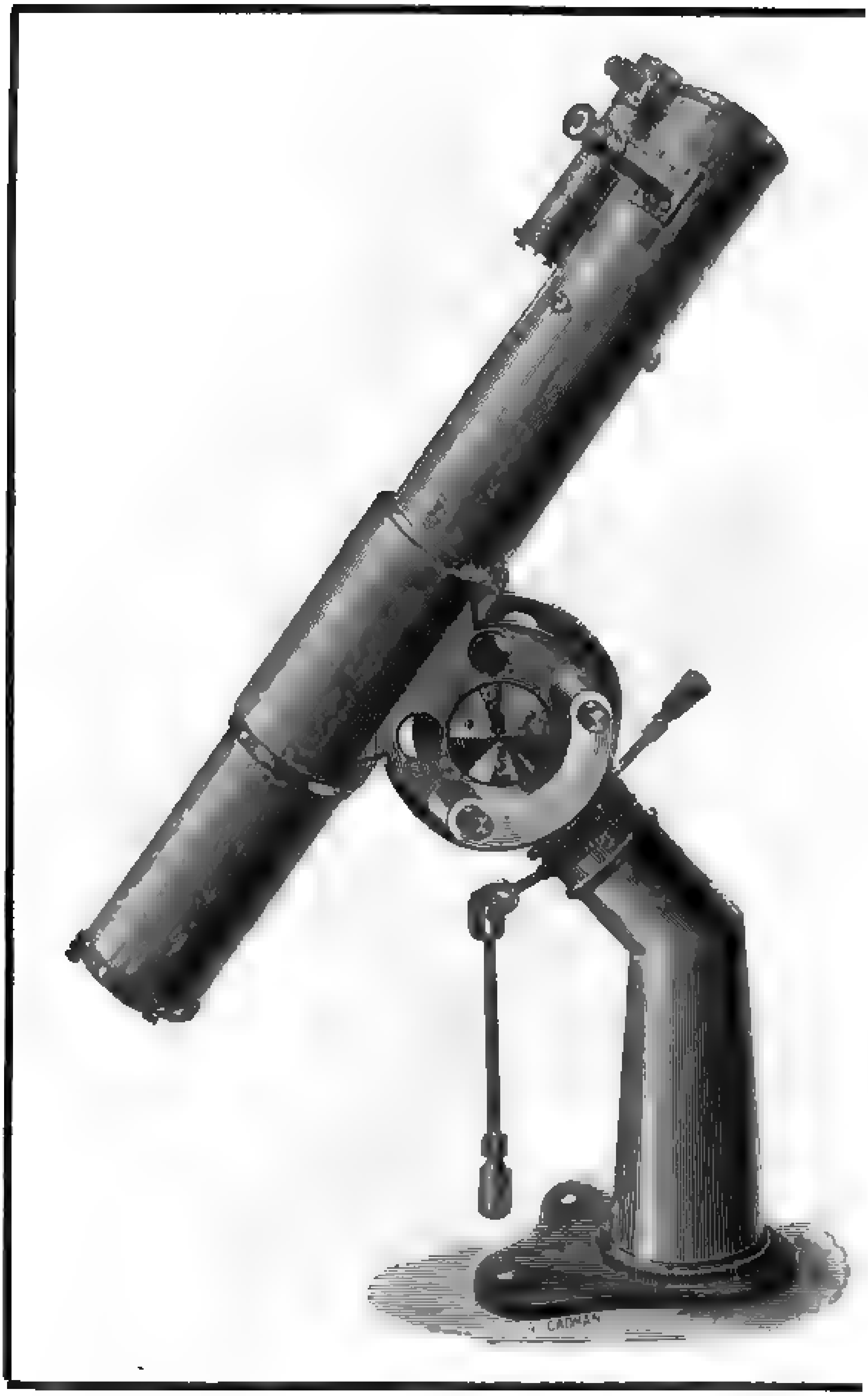


EQUATORIALLY-MOUNTED REFLECTOR.

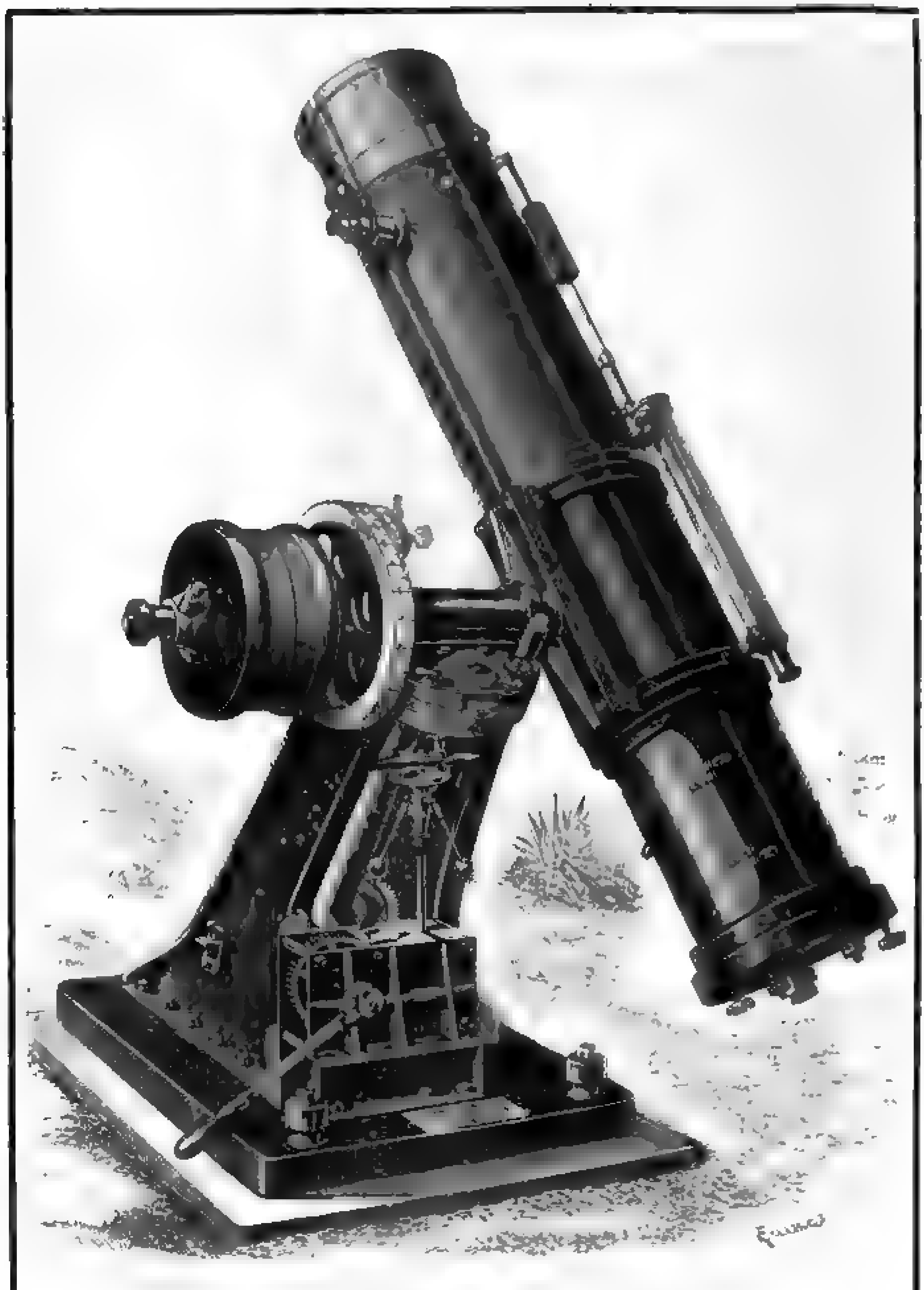
(By Browning.)

Aperture, $10\frac{1}{4}$ in.

Fig. 243. *Plate* XXXII.



BERTHON'S EQUATORIAL FOR REFLECTORS.



EQUATORIALLY-MOUNTED REFLECTOR.

(The property of Lord Lindsay.)

Aperture, 12¼ in.

at F F; a clamp screw is provided, but in any drawing this will be hidden by the spur-wheels. When this screw is eased the angle of the polar axis may be changed at pleasure and the axis moved from a horizontal to a nearly vertical position, or it may be brought to any intermediate position and there clamped and finally adjusted by the capstan-headed screws F F. D is a clock which by means of a bevelled spur-wheel gives motion to a wheel which revolves round the centre on which the polar axis turns at E. This wheel imparts motion to 2 other wheels and through them turns the driving screw on the hour-circle G G and so drives the instrument. As the wheel E runs loose on the spindle, and the distance between the wheel driven by E and the driving screw on the hour-circle remains unaltered, it is evident that a change in the inclination of the polar axis does not interfere with the motion communicated to the hour-circle by the clock [e].

Fig. 243 is that of an equatorial mounting devised by the Rev. E. L. Berthon. I have been unable however to obtain any information as to its merits or the contrary.

[e] *Month. Not.*, vol. xxxii. p. 41. Dec. 1871. A very simple and effective way of deriving an approximately equatorial motion from an altazimuth motion has been submitted by Lord Lindsay to the Royal Astronomical Society (*Ast. Reg.*, vol. xiv. p. 154. July 1876).

CHAPTER IV.

THE TRANSIT INSTRUMENT.

Its importance.—Description of the Portable Transit.—Adjustments of the Transit.—Four in number.—Method of performing them.—Example of the manner of recording Transit observations of Stars.—Of the Sun.—Remarks on observations of the Moon.—Of the larger Planets.—Mode of completing imperfect sets of transit observations.—The uses to which the Transit Instrument is applied.

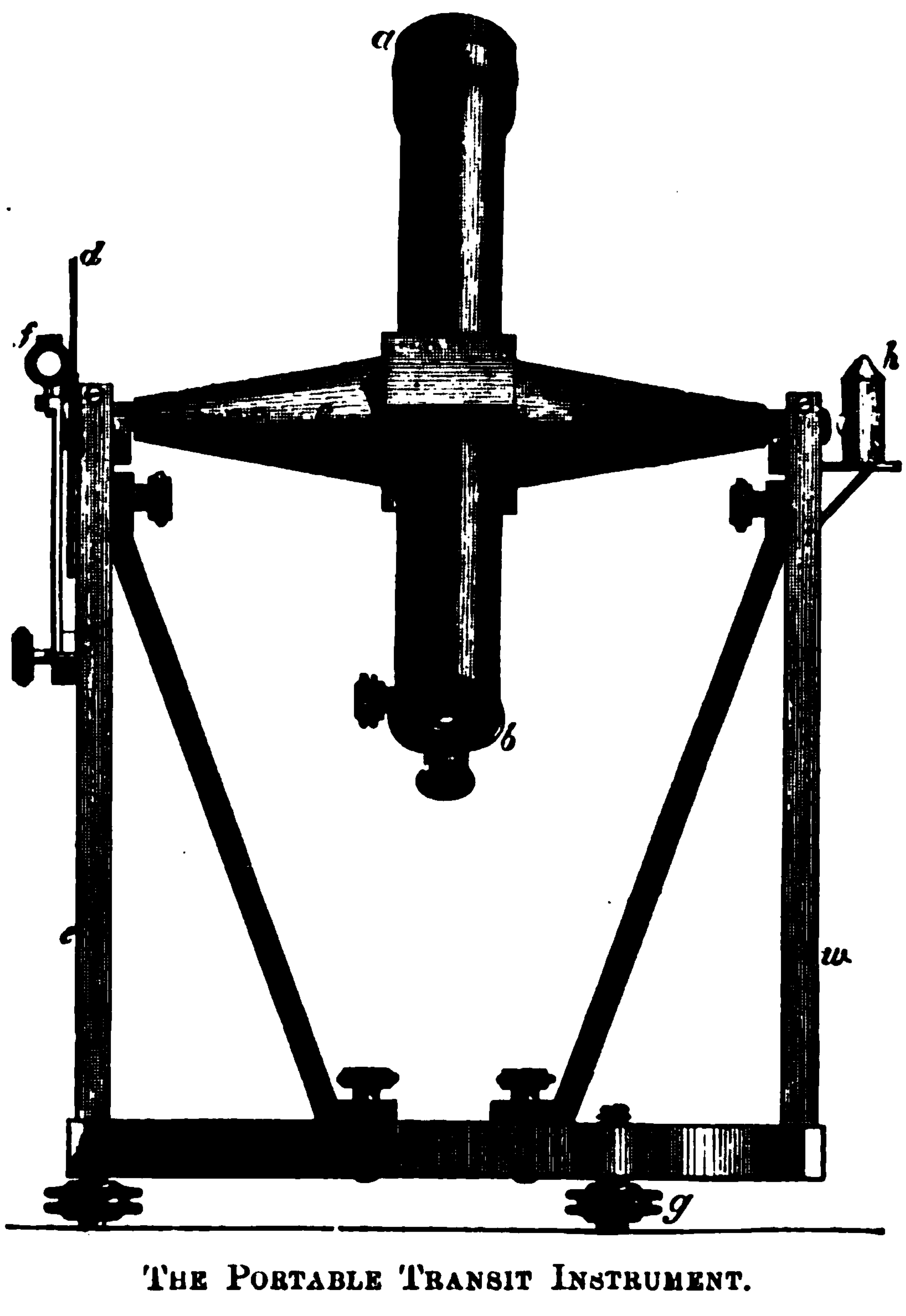
BY far the most important of the astronomical instruments used in a permanent observatory is the Transit, or Transit-Circle, the smaller and less perfect kinds being chiefly used for taking the time, and the larger for measuring the positions of stars, &c., for forming catalogues.

I shall only describe the small, or Portable Transit.

The instrument consists of 3 principal parts—the telescope, the stand, and the circle: *a b* is a telescope of a large field and low power, the tube of which is in 2 parts, which are connected by a cubical centre-piece, into which, at right-angles to the optical axis, are fitted the larger ends of 2 cones *c*, *c*, which form the horizontal axis of the telescope; the smaller ends of each cone are accurately ground to 2 perfectly equal cylinders or pivots. These pivots rest on Y's, angular bearings, which surmount the 2 side standards, *e* and *w*, of which *e* may be called the eastern, and *w* the western. One of the Y's is fixed in a horizontal groove, so that by means of a screw a small azimuthal motion may be imparted to the instrument; in like manner a small motion in altitude may be obtained by turning the foot-screw *g*. On one end of the axis is fixed, so that it may revolve with it, a declination (or "setting") circle, *d*, divided to degrees and read by verniers to minutes, &c.

Over this is fixed a level, *f*. The other cone is hollow, in order that light coming from the lamp, *h*, may pass to the centre-piece, where there is a plane pierced mirror inclined at an angle of 45°, which reflects the light to the wires placed in the principal focus. There are usually 4 or 6 wires; in the former case, 1 is placed horizontally and 3 vertically; in the latter, 1 horizontally and 5 vertically. The lamp is furnished with a sliding diaphragm,

Fig. 245.



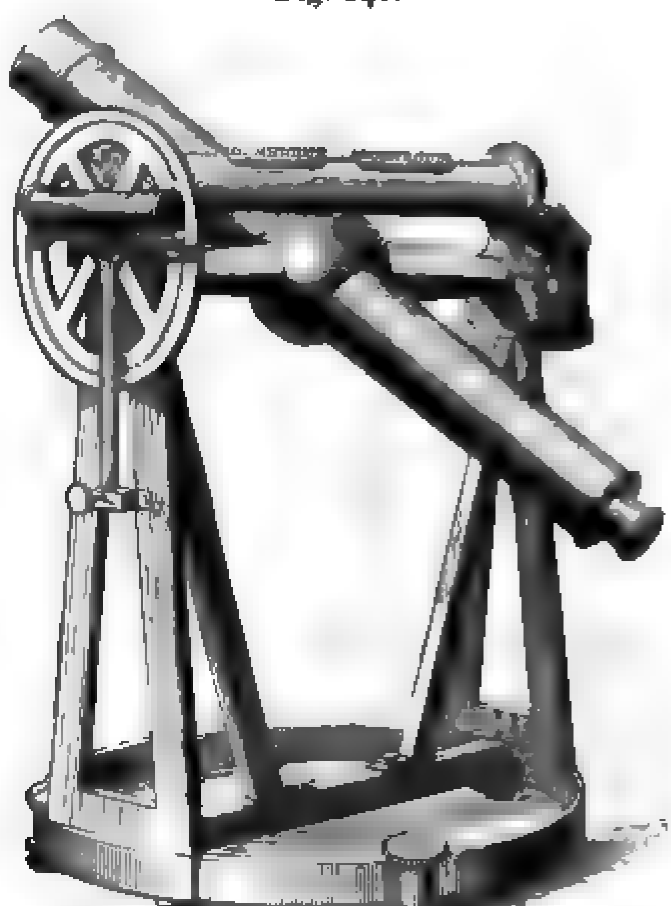
THE PORTABLE TRANSIT INSTRUMENT.

by which the quantity of light allowed to pass out may be increased or diminished as may be required.

Fig. 246 represents a Transit instrument by Browning. It does not differ from the ordinary form, but the engraving serves to shew the appearance of these instruments from another stand-point. A striding level is furnished with the instrument, to be used, when required, for adjusting the axis.

It is needless to say that it is of paramount importance that all the parts should be perfectly rigid and free from the slightest flexure, for this would vitiate the observations.

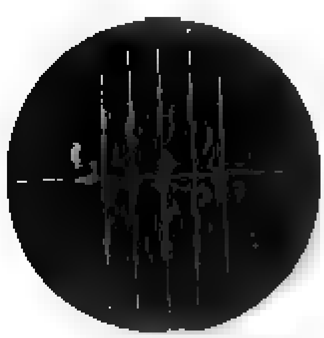
Fig. 246.



The Portable Transit Instrument.

The transit adjustments are 5 in number*. For correct observation it is necessary—

Fig. 247.



Arrangement of Wires in a Transit Instrument.

1. *That the wires and the object be in focus.* [Unless this is so, a lateral movement of the observer's head will cause a similar apparent movement of the wires.] This is called the adjustment for *parallax*.

2. *That the axis on which the telescope moves be horizontal.* This is the adjustment in *level*.

3. *That the line of sight move in a vertical circle, perpendicular to the horizontal axis.* This is generally called the adjustment of the line of collimation.

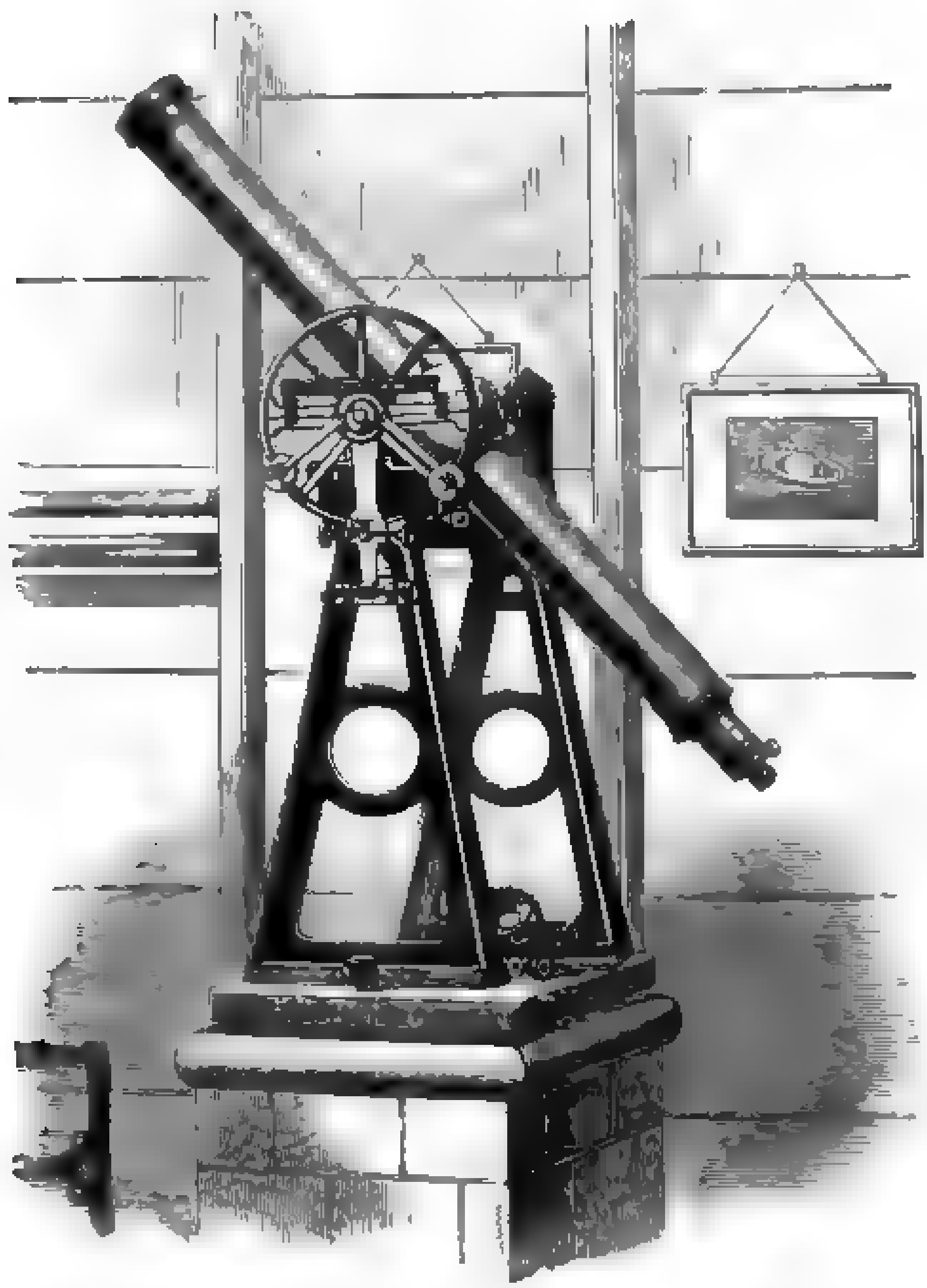
* As this volume is designed mainly for amateurs, and as amateurs rarely make use of the transit instrument for any other purpose than that of determining the time, transit-observation corrections, and expedients of a technical character, required for the work of large observatories, will be passed over. For these see Loomis's *Pract. Ast.*, pp. 39-82.

4. *That the vertical circle thus described coincide with the plane of the meridian.* This is the adjustment for azimuth.

5. *That the wires be truly vertical after the foregoing adjustments have been performed.*

1st adjustment. *Parallax.* Focus the wires accurately by means

Fig. 248.



THE TRANSIT INSTRUMENT OF THE UCKFIELD OBSERVATORY.

of the moveable tube which carries the eye-piece; turn the telescope on some well-defined and distant object; and if on moving the eye laterally the object still remains bisected or covered, as the case may be, the instrument is in adjustment for parallax. If, however, the object appears to move with respect to the wires when the eye

moves, the wires must be shifted in the tube[b] experimentally till the parallax be destroyed. This adjustment frequently occasions some trouble, but when once properly performed it should seldom require renewal. The maker ought to attend to it.

2nd adjustment. *To make the axis on which the telescope moves to be horizontal.*

Place upon the pivots the striding level, and bring the air-bubble to the centre of its run by turning the screw which is under one of the pivots or one of the standards (see Fig. 245). Turn the level, end for end, and if the bubble retains its middle position the axis is horizontal, but if it does not it must be brought back, half by the pivot-screw and half by the small vertical adjusting-screw at one end of the level. The operation must be repeated several times if needs be, till the result is satisfactory[c].

3rd adjustment. *To make the line of sight move in a vertical circle perpendicular to the horizontal axis.*

Turn the telescope on some distant, small, and well-defined terrestrial object, and bisect it with the centre wire, giving to it, if necessary, an azimuthal motion by means of the screw. Elevate or depress the telescope to see whether the object still remains bisected in every part by the middle wire; if not, loosen the screws which hold the eye-end of the telescope in its place, and turn the end round very carefully until the error is removed. Lift up the whole instrument bodily from the Y's and reverse it, end to end: if the object is still bisected by the centre wire, the collimation in azimuth is perfect; but if not, move the centre of the cross wires half-way towards the object by turning the small screws which hold the wire plate, and if this half-distance has been correctly estimated, the operation of adjustment will be complete. Again bisect the object by the centre of the cross wires by turning the azimuthal screw, and repeat the operation till the object is bisected by the centre of the cross wires in both positions of the instrument, and then the adjustment will be known to be perfect.

4th adjustment. *To make the vertical circle, described by the telescope when moving on its horizontal axis, coincide with the plane of the meridian.*

[b] The correction would be obtained by letting alone the wires and shifting the object-glass instead, but common sense dictates which is the better expedient.

[c] It is here assumed that the level itself is in order. Tests connected with levels will be found in Loomis's *Pract. Ast.*, pp. 46–7.

The axis of rotation being truly level, and the line of sight (or collimation) describing a great circle, the vertical circle passes through the zenith, and therefore cuts the meridian; if, then, we can make it touch another part of the meridian, it follows that it will everywhere coincide with the meridian.

Choose 2 stars differing but little in R. A., one crossing the meridian in or very near the zenith, the other as near the S. horizon as may be. The axis of the instrument being supposed level, the vertical circle will pass through the meridian at the zenith, however far removed therefrom at the horizon. A star *in* the zenith will therefore appear to cross the meridian at the time it actually does cross, but such will not be the case with a star remote from the zenith. If the low star passes the meridian too early, as compared with the computed time of transit, the plane of the instrument deviates to the E.; if it passes too late, the plane deviates to the W. In either case the error must be corrected by the azimuth-screw, until stars at all altitudes indicate the same amount of clock-error.

The reason why the stars selected should differ but slightly in R.A. is that the clock employed may not be going uniformly, and therefore the observer, if he finds a discrepancy, will have no means of deciding what proportion is due to error in azimuth and what to error in the rate of his clock; therefore by taking stars which pass the meridian in immediate succession, chances of error from the latter cause are reduced to a minimum.

I have explained now all that is *essential* to this method: repeated star observations, and repeated trials of azimuthal-screw turning, will enable the observer to bring his instrument into perfect adjustment; but if he is not averse from a little calculation, *one* pair of stars will enable him to complete the adjustment. And if bad weather comes on, it may be convenient to know how to do this.

Take the difference between the observed times of passage of the 2 stars, and also the difference of their computed Right Ascensions (calling the differences + when the lower star precedes the higher, and − when it follows it); if these differences be exactly equal, the instrument is exactly in the plane of the meridian: if they are not equal, their difference (that is to say, the difference of the observed times of transit *minus* the difference

of the computed Right Ascensions) will point out a deviation from that plane to the E. of S. when it is +, and to the W. when it is —.

Let δ be the difference of times *minus* the difference of R.A., π and π' the North Polar distances of the higher and lower stars, and λ the latitude of the place of observation; then x, representing the deviation of the instrument in seconds of time, will be found by the formula—

$$x = \delta \sin \pi \sin \pi' \operatorname{cosec} (\pi - \pi') \sec \lambda.$$

Or, in words[d], To the log. of the difference of times, *minus* the difference of R.A.'s, add the log. sin. of the N.P.D. of the higher star, the log. sin. of the N.P.D. of the lower star, the log. cosec. of the difference of the N.P.D.'s, and the log. sec. of the latitude. The sum will be the log. of the azimuthal deviation, which, multiplied by 15, will be the deviation in arc.

The value of a revolution of the azimuthal screw must next be determined.

Note the sidereal time of the passage of an equatorial star across the centre wire; turn the screw quickly through a revolution, so as to bring the wire to the W. of the meridian, and then note the time of the second passage: the interval between these 2 passages will then be the value in time of 1 revolution of the screw. Reduce this to arc by multiplying by 15 sin. N.P.D.

The following modification of this method will yield a better result at the cost of a little more trouble:—

Determine the clock-error by 3 or 4 stars of nearly the same declination, and following one another in as close succession as possible, in order to eliminate chances of error through want of uniformity in the rate of the clock. Turn the azimuthal screw through several revolutions, and take a second batch of stars; then the difference of the clock-error shewn by the two sets, divided by the number of revolutions, will be the value of 1 revolution. Reduce as before.

[d] The lower star may be near the *Northern* horizon, so far as the principle of this rule is concerned; but as practically a Southern star is preferable, and it is possible to abbreviate the expression of the rule by confining one's attention to such a star, the terms of the above method are modified accordingly.

The value of 1 revolution, and the azimuthal deviation by the former portion of the calculation being known, the instrument may be readily brought into the meridian. Then another pair of stars should be taken to ascertain the result of the operations.

EXAMPLE.

Observations taken at East Bourne, Sussex, July 11, 1858:—

		Observed Passage. h. m. s.		*Naut. Alm.* h. m. s.
High star, α Coronæ	..	15 28 6·26	..	15 28 40·41
Low star, θ Ophiuchi	..	16 6 20·50	..	16 6 53·83
		−38 14·24		−38 13·42
		−38 13·42		
		−0·82 Discrepancy.		

Therefore the instrument was W. of S.

Discrepancy 0·82^s		..	log.	=	9·9138139
π = N.P.D. of α Coronæ	62° 48′	..	log. sin.	=	9·9491051
π' = N.P.D. of θ Ophiuchi	93° 19′	..	log. sin.	=	9·9992720
$\pi' - \pi$ = diff. of N.P.D.	30° 31′	..	log. cosec.	=	0·2943167
λ = lat. of East Bourne	50° 46′ 22″	..	log. sec.	=	0·1990088
			2·2674^s	=	0·3555165
			15		
			113370		
			22674		
			34·0110		

Therefore the azimuthal deviation was 34·01″ W. of S.

The following will be found convenient pairs of stars for latitudes in the south of England, say 50° N.:—

α Cassiopeiæ, β Ceti.	α Hydræ, θ Ursæ Majoris.	γ Draconis, μ^1 Sagittarii.
α Ursæ Majoris, θ Ceti.	γ Ursæ Majoris, ϵ Corvi.	ρ Capricorni, α Cygni.
α Persei, ϵ Eridani.	α Canum Venaticorum, α Virginis.	α Cephei, β Aquarii.
ϵ Leporis, α Aurigæ.	α Libræ, β Ursæ Minoris.	α Piscis Australis, α Pegasi.
ι Ursæ Majoris, α Hydræ.	θ Ophiuchi, β Draconis.	γ Cephei, δ Sculptoris.

Finally, the verticality of the wires has to be attended to. Direct the telescope to some distant but well-defined object. If, on moving the telescope in altitude this object remains bisected equally well by the central wire from the top to the bottom of the field, the wire is perpendicular to the horizontal axis. If not, the screws holding the wire-plate must be loosened, and the plate gently shifted until complete bisection is secured: several trials may be requisite. The other vertical wires are placed by the maker as nearly as possible equi-distant and parallel to the centre one, and likewise the horizontal wires at right-angles to the vertical ones.

The instrument being thus in complete adjustment, observations may be commenced [e].

The observer being conveniently seated with the circle set to the Declination of the star to be taken, so soon as it enters the field (which with an inverting eye-piece it does on the W. side, except when below the Pole) takes from the clock a second, and continues the reckoning mentally till the star passes the first wire; if this is exactly coincident with the beat of the clock, the figure is noted down; if, however, as is usually the case, the star passes the wire between one beat and another, then the exact instant must be estimated and set down as a decimal of a second. This is to be done for all the wires, and a mean being taken a result will be obtained more trustworthy than that which would have been obtained from the centre wire singly.

The observations are then reduced as below; the sum of the seconds is multiplied by ·2 (equivalent to dividing by 5). To make the product coincide with the middle wire it may be requisite to add or subtract 12 or 24. The amended figures are then set forth in juxtaposition with the computed R.A. of the star, and the clock-error is arrived at. If the computed time be less than the observed, the clock is fast, and *vice versâ*.

Examples.

The following transits were taken at the Uckfield Observatory on Sept. 15, 1864, by 2 different observers:—

[e] With large instruments it is found preferable not to attempt to bring them into *perfect* adjustment, but when nearly so to take into account residual errors by constants of correction. The amateur who simply requires to find the time has no need to trouble himself with these niceties.

	β Draconis.		α Aquilæ.		ε Pegasi.
	m. s.		m. s.		m. s.
Wire I ..	44·4	.. ..	48·9	.. ..	11·4
„ II ..	4·5	.. ..	1·9	.. ..	23·8
„ III ..	27 24·3	.. ..	44 14·1	.. ..	37 35·9
„ IV ..	44·7	.. ..	26·8	.. ..	48·7
„ V ..	3·9	.. ..	38·4	.. ..	0·5
	121·8		130·1		120·3
	·2		·2		·2
	24·36		26·2		24·06
			− 12		+ 12
			14·02		36·06
	h. m. s.		h. m. s.		h. m. s.
R. A. of Star ..	17 27 22·63	..	19 44 12·27	..	21 37 34·32
Obs. Pass.	17 27 24·36	..	19 44 14·02	..	21 37 36·06
Clock	+ 1·73		+ 1·75		+ 1·74

The three results differ by only $\frac{1}{100}$ of a second! As the stars differed in time by 4^h, and in declination by $44°$, it was reasonable to infer that not only was the clock-rate uniform but that the instrument was also in adjustment in azimuth.

The Sun, Moon, and larger planets may be turned to account for ascertaining the time, but the observations are more troublesome and the results less trustworthy, being dependent upon the errors of the Tables of those bodies, as well as requiring an accurate knowledge of their semi-diameters.

In taking observations of the Sun, the time of the transit of its centre is the time required, but as it would be impossible to estimate this accurately, the time of each limb coming in contact with each wire is noted, and a mean then gives the required result. If only one limb be observed, to the mean of the passage over each wire must be added, or from it must be subtracted (according as the 1st or 2nd limb is observed), the duration of the passage of the semi-diameter as given in the *Nautical Almanac,* and the result must be compared with the time of the transit of centre there stated.

EXAMPLE.

The following transit was taken at the Uckfield Observatory on Sept. 16, 1864:—

	☉'s 1st limb.		☉'s 2nd limb.
	h. m. s.		h. m. s.
Wire I ..	30·0	.. .. ..	38·0
„ II ..	42·8	.. .. ..	50·0
„ III ..	11 39 54·7	.. .. ..	11 42 2·5
„ IV ..	7·8	.. .. ..	15·5
„ V ..	19·2	.. .. ..	26·8
	154·5		132·8
	·2		·2
	30·90		26·56
	+ 24		− 24
	54·90		2·56

Combining these two results :—

	h.	m.	s.	
	11	39	54·90	
	11	42	2·56	
2)	23	21	57·46	
	11	40	58·73	= Observed passage.

Then combining this with the computed passage (Right ascension) as given in the Almanac we have :—

	h.	m.	s.
R. A. of Sun	11	40	56·51
Obs. Pass.	11	40	58·73
Clock			+ 2·22

In taking transits of the Moon, the bright limb only in general can be observed [f]. The time of the centre transit can however be deduced by the use of tables.

In observing transits of the larger planets, it is recommended that one limb be observed at the 1st, 3rd, and 5th wires, and the other at the 2nd and 4th; then the mean of these observations will give the passage of the centre.

In practice it will frequently happen that owing to clouds, or other causes, the transit of an object across all the wires cannot be noted. In this case, provided the star's Declination be known, the imperfect set of observations can be reduced without difficulty to the centre wire; and thus the instant of meridian passage can be ascertained.

[f] Sometimes when the Moon is very near its full phase both limbs are observed, a correction for defective illumination being applied if necessary to one of them.

If, however, observations at corresponding wires—as for instance, the 1st and 5th, or the 2nd and 4th—have been obtained, and the angular interval between the wires is exactly the same, the time for the centre wire can be arrived at by simply taking a mean. On the other hand, supposing, as will usually be the case, that the wires observed are not only not corresponding ones, but are not all equally distant from the centre wire, a formula of reduction must be employed.

The *equatorial* intervals of the wires must first be ascertained: that is, the time occupied by stars *exactly* on the equator in passing from wire to wire.

Take a star the Declination of which is known.

To the log. of the interval occupied by the star in passing from any wire to the centre wire add the log. cosine of the star's Declination: the sum, rejecting 10 from the index, will be the log. of the equatorial intervals.

Having determined the intervals for all the wires several times over by stars of different Declinations, a mean of each may be taken and kept as a constant.

The observer is now in a position to complete an imperfect transit.

To the log. of the equatorial interval add the log. secant of the star's Declination; convert the product into its natural number, and subtract the same from, or add it to, the centre wire, according as the missing wire precedes or follows the centre one.

EXAMPLE.

By a transit of α Leonis (Declination $+ 12° 37' 36{\cdot}5''$) the following wire-intervals were found:—

I to centre	$25{\cdot}1^s$	Centre to IV	$12{\cdot}6^s$
II to centre	$12{\cdot}5$	Centre to V	$24{\cdot}5$

And on Sept. 15, 1864, observations of 16 Pegasi over 4 wires were obtained as follows:—

	h.	m.	s.
Wire I			31·7
„ II			—
„ III	21	46	58·5
„ IV			11·7
„ V			24·6

Fill in the missing wire, and deduce the error of the clock.

Here the missing wire was the 2[nd], and by α Leonis the interval between the 2[nd] and centre wires was 12·5ˢ: the equatorial interval corresponding to this must first be found:—

Interval 12·5ˢ	.. ..	log.	= 1·0969100
Decl. α of Leonis, + 12° 37′ 36·5″	..	log. cos.	= 9·9893674
		log. eq. int.	= 1·0862774

The transit can now be completed.

Interval of wires II and III	.. ..	log.	= 1·0862774
Decl. of 16 Pegasi, + 25° 17′ 41·1″	..	log. sec.	= 10·0437711
		log. 1·1300485	= 13·491ˢ

The missing wire therefore preceded the centre wire by 13·491ˢ, and the whole result[g] becomes:—

				s.
Wire	I	.. ..		31·7
,,	II	.. ..		45·0
,,	III	.. ..	46	58·5
,,	IV	.. ..		11·7
,,	V	.. ..		24·6
				171·5
				·2
				34·30
				+ 24
				58·30

	h.	m.	s.
R.A. of Star ..	21	46	56·50
Obs. Pass. ..	21	46	58·30
Clock, fast			+ 1·80

A result fairly accordant with those given on p. 677, when it is borne in mind that the equatorial interval was deduced from a single star.

The large transit instruments to be found in first-class observatories, and commonly termed "Transit-circles," are used for determining with the greatest accuracy the Right Ascensions and Declinations of heavenly bodies. For such purposes the portable Transit is hardly suited, except for approximations, its chief use being to ascertain the time and the latitude[h].

With reference to the former problem it may be well to mention a fact which probably most people know, namely, that the observed time of the passage of the Sun's centre across the meridian is only

[g] Though in the example the logarithms are taken out to 7 places of decimals, 5 are usually quite sufficient.

[h] Two papers on determining the latitude with the Transit Instrument will be found in the *Memoirs* R.A.S., vol. xxviii. p. 235 *et seq.*, 1860, but Struve's method is the best.

the instant of *apparent noon;* the time of *mean noon,* which is used in the civil reckoning of time, must be deduced from the apparent by means of an equation-of-time table[i].

The time shewn by a sidereal clock, when any celestial object crosses the meridian, should coincide with its Tabular Right Ascension. The difference, then, between the time shewn by the clock and the R.A. as tabulated is the clock-error, as before explained[k].

The following is the method for determining in the simplest way the latitude by means of the Transit Instrument:—

Observe the Pole-star when on the meridian (either culmination will do, but the upper is preferable), and make it pass along the horizontal wire; read the circle. Reverse the instrument promptly, and again read the circle, levelling the axis both before and after reversal. The two readings will give an arc = twice the Zenith Distance − twice the refraction. Halve the arc and add the correction for refraction due to altitude. This half-sum, increased or diminished by the star's Polar Distance (obtained from the *Nautical Almanac*), according as the upper or lower culmination was observed, = the star's Zenith Distance, which, subtracted from 90°, gives the latitude.

[i] See above, p. 433.

[k] For a further elucidation of the details connected with the subject of this chapter, the reader is referred to the *English Cyclopædia*, Arts and Sciences div., art. *Transit;* where will be found incomparably the best treatise on the Transit Instrument extant. It was written, I believe, by the late Rev. R. Sheepshanks, M.A.

CHAPTER V.

THE SEXTANT.

Description of the instrument.—The optical principle on which it depends.—Its adjustments.—Corrections to be applied to observations made with it.—Method of finding the Sun's zenith distance.—The artificial horizon.—To find the latitude.—To determine the time.

THE Sextant[a], sometimes called, from its inventor, "Hadley's Sextant," is a graduated arc of a circle, with certain accessories, so arranged that it can be employed to measure angular distances, especially of celestial objects. It is an instrument of great practical importance to the navigator and traveller for determining the time, the latitude, and the longitude. Though less directly an astronomer's instrument than those which we have hitherto considered, it is often valuable for purposes strictly astronomical—such as ascertaining the time, and fixing the positions of comets, from which Right Ascensions and Declinations can be derived.

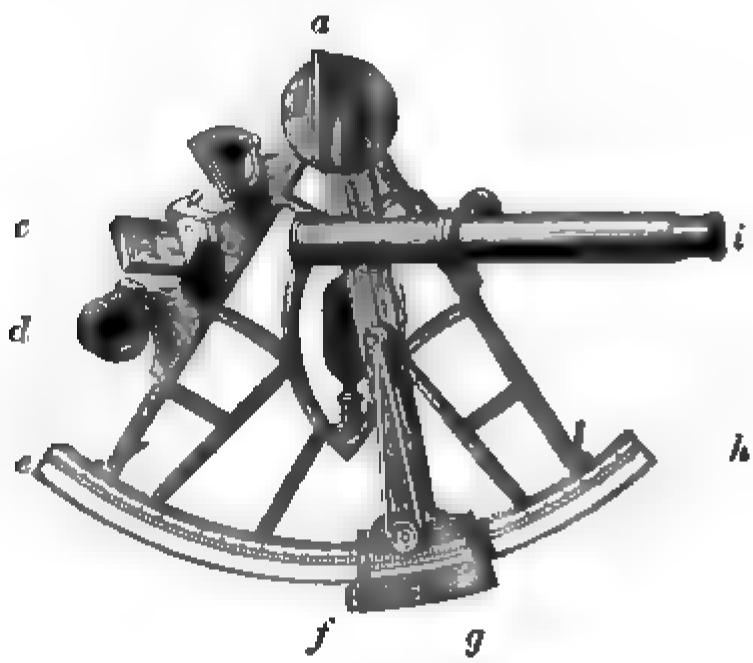
Fig. 249 is a representation of the sextant in its usual form. Its flat surface is called the *plane of the instrument*: *e h* is the arc or *limb*, reading, by the vernier attached to the moveable radius *a g*, to 30″, 20″, 15″, or 10″ (and, rarely, to 5″), as the case may be: *a* is the silvered *index-glass*, provided with screws for its adjustment. At *b* are the *fore-shades*, or screens of coloured glass: *c* is the *horizon-glass*, the lower half of which is silvered, and which also

[a] Sir J. Herschel, *Outlines of Ast.*, p. 115; *Phil. Trans.*, vol. xxxvii. p. 147, 1731; Pearson, *Pract. Ast.*, vol. ii. p. 572; *Nautical Magazine*, vol. i. p. 351; *English Cyclopædia*, art. *Sextant*; Loomis, *Pract. Ast.*, p. 96; Galbraith and Haughton, *Optics*, p. 63; Heather, *Math. Instr.*, p. 137; Simms, *Treat. on Instr.*, p. 49; Young, *Nautical Astronomy*, p. 172; Narrien, *Ast. and Geod.*, p. 98.

has screws for its adjustment. At *d* are the *back-shades* or screens, also of coloured glass: *i* is the telescope—an accessory which is not in theory an essential feature of the instrument: *a g* is the moveable radius, carrying at one end the index-glass and at the other a vernier, which radius is read by a microscope, or its equivalent. Slow motion is imparted to the radius by a tangent screw, *f*.

The principle of the sextant depends on the practical application of the following theorem in optics: *When a ray of light, proceeding in a plane at right-angles to each of 2 plane mirrors which are inclined to each other at any angle whatever, is successively reflected*

Fig. 249.



THE SEXTANT.

at the plane surfaces of each of the mirrors, the total deviation of the ray is double the angle of inclination of the mirror.

The adjustments of the sextant are 5 in number. It is necessary—

1. *That the index-glass should be perpendicular to the plane of the instrument.*

2. *That the horizon-glass should be perpendicular to the plane of the instrument.*

3. *That the horizon-glass should be parallel to the index-glass when the zero of the vernier coincides with the zero of the arc.*

4. *That the line of collimation, or the optical axis of the telescope, be parallel to the plane of the sextant.*

5. *That the index error be known.*

These several adjustments will now be described[b], as occasionally it is useful for amateur astronomers to know how to wield a sextant.

1st adjustment. *To determine whether the index-glass is perpendicular to the plane of the instrument.*

Bring the vernier to the middle of the arc, and, with the limb turned away from you, look obliquely into the mirror; then if the reflected and true arcs appear as one continued arc of a circle, the index-glass is in adjustment—*i.e.* is perpendicular to the plane of the instrument. If the index-glass is not in adjustment, the screw-driver must (but with great care) in this and other cases be called into use.

2nd adjustment. *To determine whether the horizon-glass is perpendicular to the plane of the instrument.*

With the zero of the vernier coinciding with the zero of the arc, hold the sextant *horizontally*, and, looking at the horizon, observe if the reflected and real horizons appear as one continuous or unbroken line: or, otherwise, hold the instrument perpendicularly, and look at any convenient object, such as the Sun; sweep the index-glass along the limb, and if the reflected image pass exactly over the direct image without any lateral projection, the horizon-glass is perpendicular to the plane of the instrument.

3rd adjustment. *To determine whether the horizon-glass is parallel to the index-glass when the zero of the vernier coincides with the zero of the arc.*

Hold the instrument in a *vertical* position, and through the telescope look towards the horizon, and observe if the reflected and real horizons form one continuous or unbroken line; if they do, the horizon-glass is parallel to the index-glass.

4th adjustment. *To make the line of collimation parallel to the plane of the instrument.*

Fix the telescope in its place, taking care that 2 wires are parallel to the plane of the instrument; select 2 objects (such as the Sun and the Moon, or the Moon and a bright star) more than 90° distant from each other, and bring them into contact on the wire nearest the instrument. Then slightly move the sextant, and

[b] Rosser's *Navigation*, p. 197.

see how they appear on the other wire. If they are still in contact, the line of collimation is in adjustment: but if the objects separate when brought to the farther wire, the object-glass end of the telescope *inclines towards* the plane of the sextant; if one overlies the other, the object-glass end of the telescope *declines from* the plane.

5th adjustment. *To determine the index error.*

Measure the Sun's diameter on the arc of the instrument and on the arc of excess, which is done by holding the sextant perpendicularly and bringing the real and reflected Suns in exact contact on each side of zero. *Half the difference of the 2 readings* will be the index error—which is additive when the reading on the arc of excess is the *greater*, but subtractive when the reading on the arc is the *lesser* of the 2.

To test the accuracy of these readings *off and on*, as they are called, add them together and divide the sum by 4. The quotient thus obtained should agree (approximately) with the semi-diameter of the Sun given in the *Nautical Almanac* for the day of observation. If there is a considerable discrepancy, the readings are erroneous.

Suppose that on Dec. 25, 1866, the following readings were taken:—

	′ ″		′ ″
Reading off	+34 0		34 0
Reading on	−31 30		31 30
	2) 2 30		4) 65 30
∴ Index error	+ 1 15	⊙'s semi-diameter	16 22

Presuming that his sextant is in adjustment, and its index error known, and that the altitude of some celestial object has been taken, the observer must apply several corrections before he can arrive at the true altitude of the centre of the object viewed. If the object be the Sun or the Moon, these corrections are 4 in number; if the object be a fixed star, they are only 2. In the former case the corrections are for dip, refraction, semi-diameter, and parallax; in the latter, for dip and refraction.

1. *Dip.* The correction for dip is *subtractive*, for when observations are made from the deck of a ship the sea-horizon dips, or is depressed, below the level of the sensible horizon, and makes the observed altitude to be greater than the true apparent altitude.

The following is a table of this correction :—

Height.	Dip.	Height.	Dip.	Height.	Dip.	Height.	Dip.	Height.	Dip.
ft.	′ ″	ft.	′ ″	ft.	′ ″	ft.	′ ″	ft.	′ ″
1	0 59	10	3 3	19	4 13	28	5 2	65	7 48
2	1 22	11	3 12	20	4 20	29	5 13	70	8 6
3	1 40	12	3 21	21	4 26	30	5 18	75	8 23
4	1 56	13	3 29	22	4 32	35	5 43	80	8 39
5	2 10	14	3 37	23	4 39	40	6 7	85	8 55
6	2 21	15	3 45	24	4 45	45	6 29	90	9 11
7	2 33	16	3 52	25	4 51	50	6 51	95	9 26
8	2 43	17	3 59	26	4 56	55	7 11	100	9 41
9	2 54	18	4 6	27	5 2	60	7 30	110	10 9

2. *Refraction.* The correction for refraction is also *subtractive.* For an account of this phenomenon, see *ante,* Book III; and for tables, see *post,* Book XII.

3. *Semi-diameter.* The Sun, Moon, and important planets have large discs; consequently only the limbs are observed, and in practice the lower limb by preference. To obtain the altitude of the centre we must *add* the semi-diameter to the altitude of the *lower* limb, or *subtract* it from the altitude of the *upper.* The semi-diameters of the Sun, Moon, and principal planets are given in the *Nautical Almanac* for each day of the year.

4. *Parallax.* The correction for parallax is *additive,* for in the case of the Sun, Moon, and planets, the altitude taken on the Earth's surface is less than what it would be if our observations were made at the same moment, at the Earth's centre, and the altitude were measured from the rational horizon; and this difference between the apparent and the geocentric place of a celestial body is its parallax in altitude. When the body is in the horizon the parallax (then called the *horizontal parallax*) is greatest: in the zenith it vanishes altogether. The fixed stars, owing to their great distance, have no horizontal parallax: that of the Sun is about 9″; that of the Moon is not only a large, but it is also a variable quantity, varying between the limits of about 61½′ and 54′; that of Mars may amount to 24″; and that of Jupiter to 2″.

The following is a table of the Sun's parallax in altitude:—

Alt.	0°	12°	15°	30°	33°	39°	42°	48°	51°	57°	60°	66°	69°	72°	75°	78°	81°	84°	90°
Par.	9″	9″	8″	8″	7″	7″	6″	6″	5″	5″	4″	4″	3″	3″	2″	2″	1″	1″	0″

The horizontal parallax of the Moon will be found in the *Nautical Almanac.*

The following is a summary of the corrections to be applied to an observed altitude of the Sun:—

1. *Index error;* + or −.
2. *Dip;* always −.
3. *Refraction;* always −.
4. *Semi-diameter;* + or −.
5. *Parallax;* always +.

FROM THE OBSERVED ALTITUDE OF THE SUN TO FIND THE SUN'S ZENITH DISTANCE.

I. *Apply the corrections needful for obtaining the true altitude.*

II. *Subtract the true altitude from 90°, and the remainder is the zenith distance.*

EXAMPLE.—Jan. 1, 1867. Given, the observed altitude of the Sun's lower limb, 40° 20′ 30″; index error, 2′ 50″ subtractive; height of eye, 18 feet. To find the true altitude, and thence the zenith distance of the Sun's centre.

I.

+ Corrections.	′ ″	− Corrections.	′ ″
Parallax	+ 0 7	Index error ..	− 2 50
Semi-diameter ..	+ 16 18	Dip	− 4 6
		Refraction.. ..	− 1 8
	+ 16 25		− 8 4
	− 8 4		
	+ 8 21		

	° ′ ″
Sun's observed altitude	40 20 30
Corrections	+ 8 21
Sun's true altitude	40 28 51

II.

	°	′	″
	90		
Sun's true altitude	40	28	51
∴ Sun's zenith distance	49	31	9

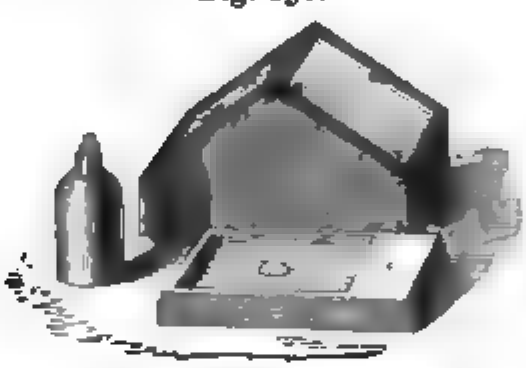
*** When the Sun is N. of the observer the zenith distance is S., and *vice versâ*.

The procedure in dealing with the Moon, a large planet, or a star, is, *mutatis mutandis* according to what has already been stated, the same.

A word about the "artificial horizon."

This is a mere rectangular platform, of an area of 20 or 30 square inches, with raised sides and supported (sometimes) on 4 feet, two of them provided with coarse adjusting-screws for levelling.

Fig. 250.



The Artificial Horizon.

Over the whole fits a case, with a sloping roof covered with sheet glass (the two surfaces of which must be absolutely parallel), to protect from wind the platform, on which is poured out the quicksilver which forms the horizon.

When an artificial horizon is used, the *dip* does not affect the observed altitude of a heavenly body, but the angle read off is the *double* of the actual angle of altitude. Therefore—

TO OBTAIN THE TRUE ALTITUDE OF A HEAVENLY BODY FROM OBSERVATIONS WITH AN ARTIFICIAL HORIZON.

I. *To the observed angle apply the index error.*

II. *Divide the sum or the remainder by 2, and the quotient will be the apparent altitude.*

III. *Then apply the several corrections for refraction, semi-diameter, and parallax, as the case may require.*

It seems needless to offer an example of so simple a rule.

TO FIND THE LATITUDE.

This is both an astronomer's and a navigator's problem, and each uses[*] a method which is not naturally open to the other.

* Or 'generally finds it convenient to use,' for there are various methods *possible*.

The astronomer, in a fixed observatory, employs a fixed instrument (the Transit) and an artificial horizon; the navigator, always in motion, employs a portable instrument (the sextant) and the natural horizon. But an astronomer may, and often does, work with a sextant: therefore, for the use of astronomers, I shall give a simple sextant method which is also available for travellers in foreign climes.

The observations for altitude of a circumpolar star at its upper and lower transits furnish the best (and at the same time the simplest) method of determining the latitude, because the observer is independent of uncertainty in the value of the star's Declination, and, to a very large extent, is independent of refraction also.

The first and most delicate stage in the operation is to obtain a zero point from which to measure the angular distance of the star. There are three zero points available, any one of which may be employed according to the taste of the observer; viz. the zenith, its correlative the nadir, and the horizon: the first two are in practice derived from the vertical floating collimator, and the third indifferently from the horizontal floating collimator or the artificial horizon. On the whole, the amateur astronomer working with a Transit Instrument will find it most convenient to use the artificial horizon, but the other instruments named will be alluded to hereafter (see *post*).

A traveller's method of determining the latitude is the following:—

I. *Find the true zenith distance of the Sun's centre* [as in the process on p. 687].

II. *Convert the local apparent time into Greenwich apparent time* [the means of ascertaining local apparent time will be explained presently], using the table *post*, Book XII, to turn the longitude into time.

III. *Correct the Sun's declination* [*Naut. Alm.*, p. I. of each month] *for the Greenwich apparent time by taking proportional parts of the diurnal change*[d].

IV. *Under the zenith distance put the corrected declination, each with its proper name* N. *or* S.

[d] In navigation books will be found a brief table of logarithms for performing this operation with celerity.

*** If both are N. or both S., add them together, and the sum is the latitude N. or S.

If one is N. and the other S., their difference is the lat.; of the same name as the greater.

When the decl. is 0° the zen. dist. is the lat.; of the same name as the zen. dist.

When the zen. dist. is 0, the decl. is the lat.; of the same name as the decl.

When the zen. dist. and the decl. are equal, but one is N. and the other S., the lat. is 0°, and the observer is on the equator.

We will now work out the foregoing rule, borrowing the materials which are to be found on p. 687.

I.

		°	′	″	
The zenith distance of the Sun's centre is ..		49	31	9	N.

II.

		d.	h.	m.
Local apparent time, Jan.		1	2	45
Longitude, 77° 30′ W.	+		5	10
Greenwich apparent time, Jan.		1	7	55

III.

		°	′	″	
Sun's Declination, Jan. 1		23	6	9	S.
„ „ Jan. 2		23	1	29	
Daily change	−		4	40	

∴ Change for $7^h\ 35^m = 1'\ 28''$

		°	′	″	
Sun's Declination, Jan. 1		23	6	9	S.
Change for $7^h\ 35^m$	−		1	28	
Declination corrected		23	4	41	

IV.

	°	′	″	
Zenith distance	41	31	9	N.
Declination corrected	23	4	41	S.
Latitude	18	26	28	

Which latitude is N.

TO FIND THE TIME.

The following convenient method for determining the time is given by Norie:—

"1. Subtract the Sun's Declination from 90° when the latitude and declination are of the same name, or add it to 90° when they are of contrary names, and the sum or remainder will be the Sun's polar distance.

"2. Add together the Sun's altitude, the polar distance, and the latitude of the place of observation; take the difference between half their sum and the Sun's altitude, and note the remainder.

"3. Then add together—

The co-secant of the polar distance.
The secant of the latitude.
The co-sine of the Half-sum.
The sine of the Remainder.
And the constant logarithm 5·30103.

"4. The sum of these 5 logarithms, rejecting tens in the index, will be the *log-rising**, answering to the apparent time from the nearest noon; consequently if the observation be made in the morning, the time thus found must be taken from 24^h to obtain the apparent time from the preceding noon. Hence the error of the watch may be found."

An example of the foregoing rule, with the several stages arranged in what will be found in practice the most convenient order, is here appended.

I.

Date	October 1, 1866.
Name of place of observation	Uckfield, Sussex.
Latitude λ	50° 58′ 0″
Longitude	24·15ˢ E.

II.

	Observed Sextant Altitudes of the Sun. ° ′	Observed times by Watch. h. m. s.
	70 53	0 9 25
	70 38	0 14 32
	70 35	0 15 51·5
	70 31	0 17 6·5
	70 24	0 20 56
	70 16	0 23 41·5
Sums	6) 423 17	6) 1 41 32·5
Means ..	70 32 50″	0 16 55·4

III.

	° ′ ″
Sun's Declination at Greenwich	3 12 7·4 S.
Correction for longitude .. .. (insignificant)	
Correction for time from noon	+ 16
Sun's true Declination at Uckfield	3 12 23·4 S.
	+90
Sun's polar distance	Δ 93 12 23·4

* For the logarithm Table thus denominated, reference must be made to a book of Navigation Tables.

IV.

		° ′ ″
Instrumental altitude of the Sun's lower limb ..		70 32 50
∴ Semi-instrumental altitude		35 16 25
Sun's semi-diameter	+	16 1.4
Correction for parallax	+	7·5
Correction for refraction	−	1 20·5
Sun's true altitude		35 31 13·4

V.

	° ′ ″
Sun's true altitude	35 31 13·4
Sun's polar distance	93 12 23·4
Latitude of Uckfield	50 58 0
Sum	179 41 36·8
∴ Semi-sum P	89 50 48·4

VI.

	° ′ ″
Semi-sum	89 50 48·4
Sun's true altitude	35 31 13·4
Remainder Q	54 19 35

VII.

			° ′ ″	
Log. cosec. (compl.)	Δ	..	(86 47 36·6) ..	0·0006806
Log. sec.	λ	..	(50 58 0) ..	0·2008164
Log. cos.	P	..	(89 50 48·4) ..	7·4271974
Log. sin.	Q	..	(54 19 35) ..	9·9097443
Constant logarithm		..	..	5·3010300
Apparent time = log-rising			..	2·8394687

h. m. s.
0 26 57·5

VIII.

		h. m. s.
Apparent solar time		0 26 57·5
		12 0 0
Apparent civil time		12 26 57·5
Equation of time	−	10 19·5
Mean time at Uckfield		12 16 38·0
„ „ by watch		12 16 55·4
Error of watch	+	17·4

In competent hands the sextant will generally give a result correct to within a few seconds.

The *Box Sextant*[f] is merely a miniature sextant, very portable, and used rather for surveying than astronomical purposes, though, in conjunction with an artificial horizon, it becomes valuable for obtaining solar time, or the latitude.

The *Prismatic Sextant*, constructed by Pistor and Martins of Berlin, differs from the common sextant, not only in its construction but in its capability, for it can measure angles up to 180°.[g]

[f] Formerly the *Snuff-box* Sextant, from the limited space it occupies *in transitu*.

[g] Loomis, *Pract. Ast.*, p. 101.

CHAPTER VI.

MISCELLANEOUS ASTRONOMICAL INSTRUMENTS.

The Altazimuth.—Everest's Theodolite.—The Mural Circle.—The Repeating Circle.—Troughton's Reflecting Circle.—The Dip-Sector.—The Zenith-Sector.—The American Zenith-Sector.—The Reflex Zenith-Tube.—The Horizontal Floating Collimator.—The Vertical Floating Collimator.—The Heliometer.—Airy's Orbit-Sweeper.—The Comet-Seeker.—The Astronomical Spectroscope.

THOUGH the Transit Instrument and the Equatorial are the most important instruments used in astronomy, there are several others of an astronomical or semi-astronomical character, which should at least be glanced at in a work like the present. Still, as they are but rarely required by the amateur, my mention of them will be rather for the purpose of furnishing references to other works professedly devoted to their consideration than to treat of them at any length myself.

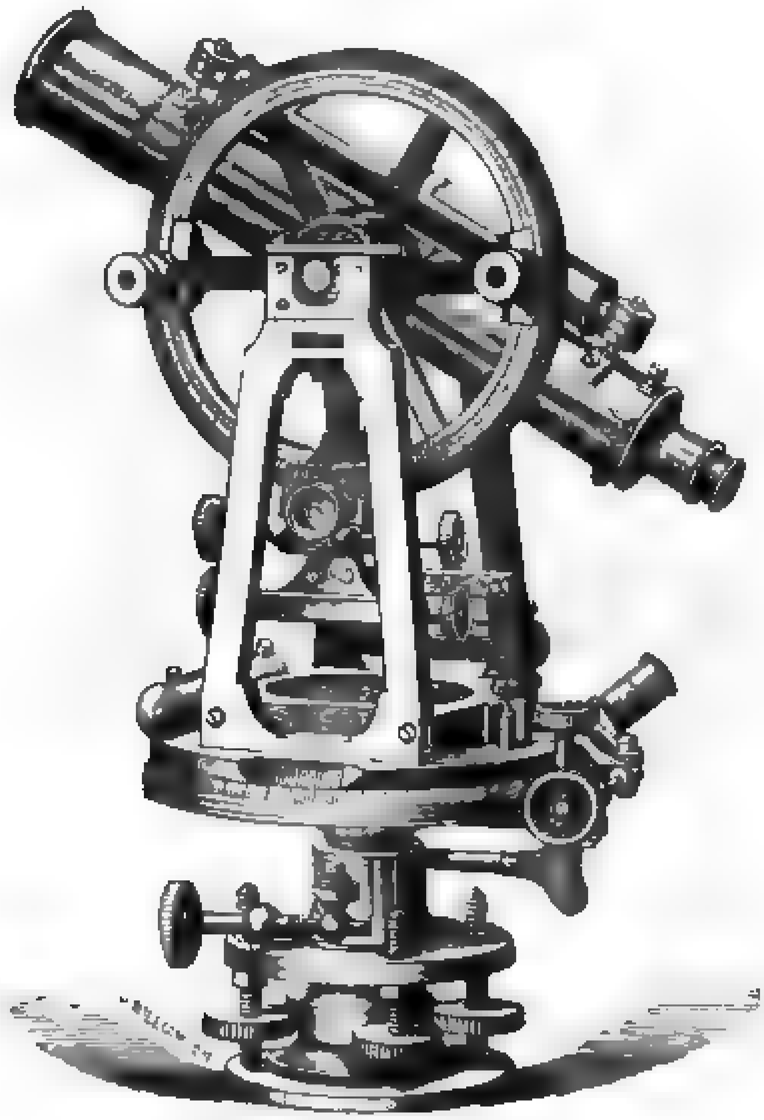
The following are the names of those instruments which I group under this head:—

1. The Altazimuth.
2. Everest's Theodolite.
3. The Mural Circle.
4. The Repeating Circle.
5. Troughton's Reflecting Circle.
6. The Dip-Sector.
7. The Zenith-Sector.
8. The Reflex Zenith-Tube.
9. The Horizontal Floating Collimator.
10. The Vertical Floating Collimator.

11. The Heliometer.
12. Airy's Orbit-Sweeper.
13. The Comet-Seeker.
14. The Astronomical Spectroscope.

The *Altazimuth*[a], as its name implies, is used for the measurement of altitudes and azimuths. It may be considered as a

Fig. 251.



THE PORTABLE ALTAZIMUTH, OR TRANSIT THEODOLITE.

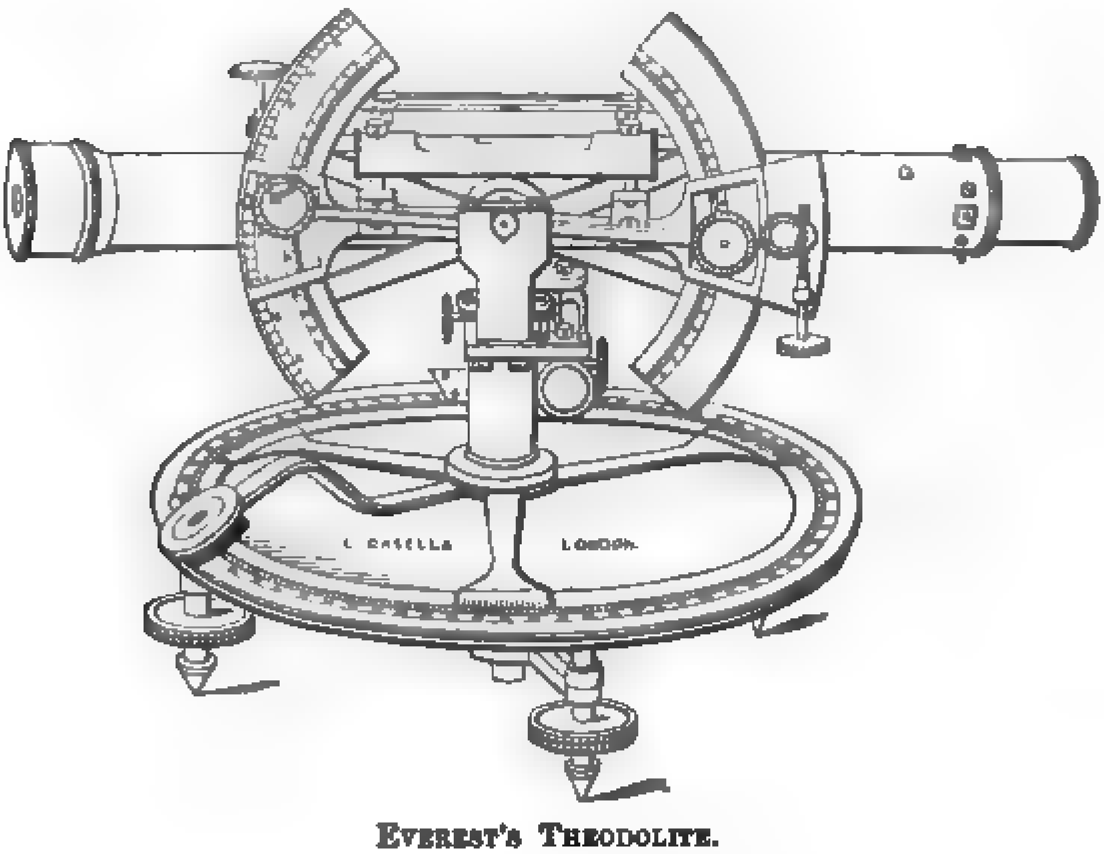
modification of the ordinary transit circle, the telescope, circle, and stand of which are capable of motion round a vertical axis. The altazimuth may therefore be used for meridional or extra-meridional observations indifferently, and when of a portable size it may in fact be regarded as a theodolite of a superior construction.

[a] Pearson, *Pract. Ast.*, vol. ii. pp. 413, 457, 472; Heather, *Mathematical Instruments*, p. 153; Simms, *Treatise on Instruments*, p. 92; *English Cyclopædia*, art. *Astronomical Circle*; Loomis, *Pract. Ast.*, p. 93; Narrien, *Ast. and Geod.*, p. 79.

The form of the instrument represented in Fig. 251 is sometimes known under the name of the *Transit Theodolite*.

Fig. 252 is a pattern of a theodolite, known as "Everest's," from its designer, the late Sir G. Everest, Director of the Indian Survey. The arrangement adopted for the graduated arcs enables the observer, it is understood, to measure minute angles with greater accuracy than is possible with an ordinary theodolite of corresponding size; and for geodetical purposes, especially in foreign countries, a maximum of precision with a minimum of weight

Fig. 252.



Everest's Theodolite.

is of course a matter of the utmost importance. This instrument can be used within certain limits of altitude as an altazimuth[b].

The *Mural Circle* consists of a graduated circle furnished with a suitable telescope, and very firmly affixed to a wall (*murus*) in the plane of the meridian. This instrument[c], which was introduced for determining with great accuracy meridian altitudes and zenith distances, may now be regarded as obsolete, having been superseded by the Transit Circle.

The *Repeating Circle* is employed for the measurement of angular

[b] Simms, *Treatise on Instruments*, p. 20.

[c] Pearson, *Pract. Ast.*, vol. ii. p. 472; *English Cyclopædia*, art. *Astronomical Circle*; Loomis, *Pract. Ast.*, p. 83; Breen, *Pract. Ast.*, p. 432; Narrien, *Ast. and Geod.*, p. 76.

distances, both of celestial and terrestrial objects. The principle consists in repeating the readings of an angle several successive times and taking a mean, and thus eliminating almost wholly the errors due to defective graduation. Invented about the year 1744 by T. Mayer, this instrument was first constructed in France, under the superintendence of Borda, some time between 1780 and 1790, and in that country it was much used. In England, however, it was never popular, firstly, because when it was invented the graduation of English instruments was so much superior to those of foreign make as to render it less needed; and secondly, because of the labour involved in working with it. Its value (theoretically very considerable) would seem to be impaired in practice by some defects which Sir J. Herschel, though he speaks of them as unknown, connects with imperfect clamping[d].

Troughton's Reflecting Circle is a different adaptation of the principle involved in the sextant. It consists of a complete graduated circle, having the telescope and reflector on one side of the circle whilst the graduations and verniers (3 in number) are on the other. A reading being taken by each vernier, the mean of the three readings gives a more accurate result than would any one singly. In Sir J. Herschel's opinion "this is altogether a very refined and elegant instrument[e]."

The *Dip-Sector*, another instrument of Troughton's invention, is used for determining the dip of the horizon. The principle of it is similar to that of the sextant[f].

The *Zenith-Sector* serves to determine the zenith distances of stars. It is, especially as modified by Airy, chiefly used in geodetical operations; but it was invented by Hooke about the year 1669, to ascertain whether the Earth's orbit afforded any sensible parallax[g].

A form of zenith telescope used by the officers of the United States Coast Survey and preferred by them to Airy's Zenith-Sector, is represented in Fig. 253. It was devised originally by Captain

[d] *Outlines of Ast.*, p. 119; Brewster's *Cyclopædia*, art. *Circle*; *English Cyclopædia*, art. *Repeating Circle*; *Memoirs* R.A.S., vol. i. p. 33; Pearson, *Pract. Astron.*, vol. ii. p. 578; Loomis, *Pract. Astron.*, p. 103; Breen, *Pract. Astron.*, p. 381.

[e] Pearson, *Pract. Ast.*, vol. ii. p. 586; Simms, *Treat. on Instr.*, p. 57; Heather, *Math. Instr.*, p. 141.

[f] Simms, *Treat. on Instr.*, p. 65.

[g] Pearson, *Pract. Ast.*, vol. ii. p. 531; *Month. Not.*, vol. v. p. 188; Narrien, *Ast. and Geod.*, p. 83.

Talcott to carry out practically the principle based upon the proposition that when the meridian zenith distances of two stars

Fig. 253.

Zenith Telescope of the U. S. Coast Survey.

at their upper culmination (one being N. and the other S. of the zenith) are equal, the colatitude is the mean of their N.P.D.'s. It is therefore necessary, to avoid arc readings, that the telescope when pointed to any zenith distance should be capable of revolution on a vertical axis. And as two stars could rarely be found having the same meridional zenith distance, those are selected in pairs (N. and S.) which culminate within a few minutes of time and within 20′ of arc of zenith distance of each other, and the difference of meridional zenith distance is measured by a micrometer, and change of verticality by a delicate level. Stops are clamped on the azimuth circle to denote when the instrument is in the meridian. The telescope is set to the nearest minute of the apparent mean zenith distance of the two stars; the star is bisected at culmination by the micrometer line, and the micrometer and level are read. Then the telescope is revolved through 180° and the second star observed in the same manner. The American officers allow 5 minutes between the 2 stars of every pair, and when the double observation is complete 7 minutes before another is commenced. Accuracy in the results depends on the delicacy of the level and of the micrometer[h].

The *Reflex Zenith-Tube* is used at Greenwich for observations of the star γ Draconis by reflection in a trough of mercury. It was invented by Airy[i].

The *Horizontal Floating Collimator* and the *Vertical Floating Collimator* are two instruments of similar principle, and of not very different construction, designed to facilitate the adjustment of circles. The former is used for determining the horizontal point, and the latter the zenith or the nadir points, as the case may be. Each kind consists of a telescope (with a system of cross wires in its field) which is either made to rest in a horizontal position on a plate of iron floating on a surface of mercury; or is fixed vertically in a frame, at the lower part of which is an iron ring the plane of which is at right-angles to the axis of the telescope, the ring floating on mercury in an annular vessel. The telescope of the circle which it is desired to adjust being duly put in position, the observer looks through it, either downwards or upwards (as the case may be), to the telescope of the collimator, which in the vertical in-

[h] *Month. Not.*, vol. xxviii. p. 181. April 1868; Chauvenet, *Pract. Ast.*, p. 350.

[i] A full description of it is given in the *Greenwich Obs.*, 1854.

strument is mounted with its axis coincident with the axis of the ring. The adjustment consists in bringing the cross wires of the two telescopes to a mutual intersection, by the screw movements of the circle. These instruments were both invented, or perhaps it would be more reasonable to say contrived, by Captain Kater, but the vertical one is that to which the preference is usually given[k].

The *Heliometer*[l] is a large telescope mounted equatorially in the usual way, but with its object-glass divided into two equal parts by a section across the centre. The parts of the object-glass are capable of motion in their own planes, through considerable intervals, by means of screws, and thus their optical centres can be separated by a greater or less space. As each half-glass forms a separate image of any object, the two images will be at an angular distance dependent on the amount of the separation of the centres of the two half-glasses. By proper management the angular distances of two objects not very far apart can thus be determined[m].

Orbit-Sweeper is the name given by Airy to a contrivance which he thinks will meet an acknowledged difficulty. A comet or planet is known by previous calculation to be pursuing a certain and tolerably definite track through the heavens, but its actual position at any given time is unknown. To sweep for such an object an unmounted telescope is of little or no use, and an equatorial is hardly more suitable, unless the path of the object be continuously through the same parallel of declination eastwards and westwards, or through the same hour of right ascension, northwards and southwards—a condition which it is scarcely necessary to mention never subsists, unless it be for a very limited period of time, the apparent course of celestial objects, whether planets or stars, being almost always *inclined.*

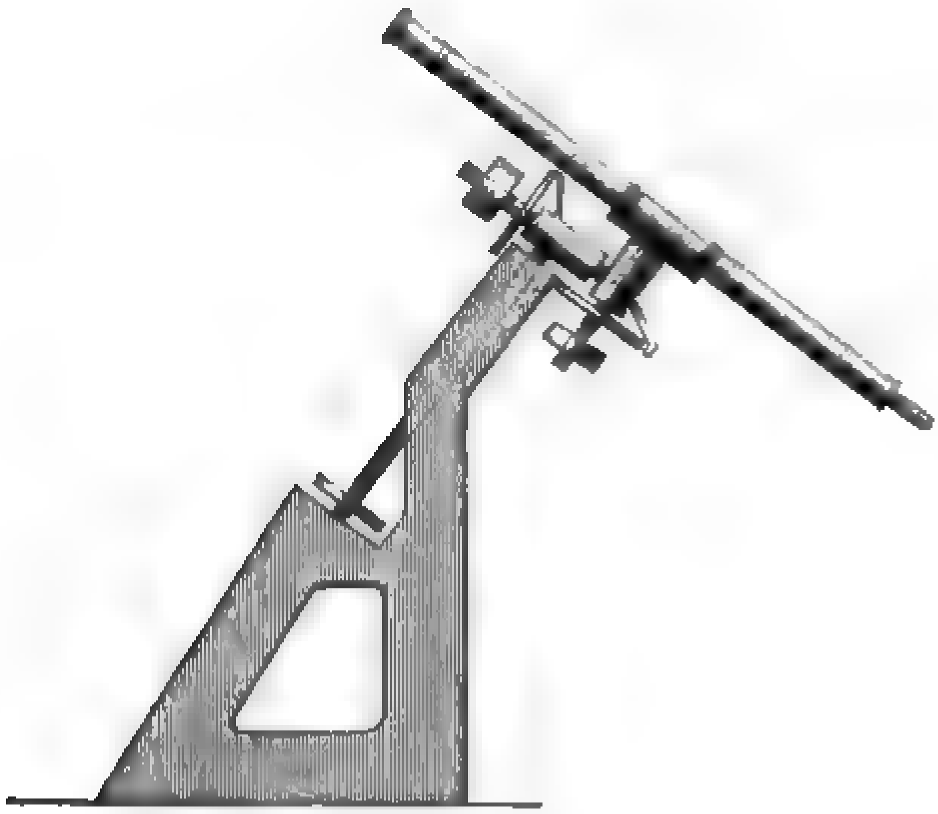
[k] *Phil. Trans.*, vol. cxv. p. 147, 1825; *ibid.*, vol. cxviii. p. 257, 1828; *English Cyclopædia*, art. *Collimator;* Pearson, *Pract. Ast.*, vol. ii. p. 446; Herschel, *Outlines of Ast.*, p. 107.

[l] ἥλιος *the Sun*, and μέτρον *a measure;* so called because the instrument was first used to measure the Sun. Being now employed for various other purposes the name is not an appropriate one. The elder Dollond called it the *divided object-glass micrometer*, and De Charmères (a French naval officer of the last century, who has some claim to be regarded as its inventor) a *megameter*, in opposition to *micrometer*.

[m] *Radcliffe Observations*, vol. xi.; *Speculum Hartwellianum*, p. 156; Weale, *London*, p. 677.

It is to follow by one motion this inclined path that Airy's new instrument is designed. It resembles a German equatorial the polar axis of which is of a greater length than usual, and which works for some distance at its upper end in a tubular bearing. The declination, or cross, axis, carries at one end a counterbalance, and at the other, not, as in the regular equatorial, the telescope, but a small trunk in which a second and smaller cross axis turns; to one end of this is attached a counterbalance, and to the other the telescope.

Fig. 254.



AIRY'S ORBIT-SWEEPER.

"By giving a proper position in rotation to the first cross-axis, the inclination of the second cross-axis to an astronomical meridian may be made any whatever, and therefore the inclination of the circle in which the telescope will sweep may be made any whatever; and it may be made to coincide with the definite line drawn on the celestial sphere in which the comet is to be sought."

The inventor thinks that an instrument of this kind would be found of great service to lunar photographers, as the difficulty of following the Moon with an equatorial is well known[n].

The *Comet-Seeker* is merely a cheap equatorial provided with an

[n] *Month. Not.*, vol. xxi. p. 159. March 1861.

inferior object-glass and coarsely-divided circles, and optically contrived so as to possess an unusually large field in comparison with its aperture. It is an instrument more frequently met with in Germany than in this country.

The application of the *Spectroscope* to astronomical purposes is comparatively recent.

A spectroscope in its simplest conception consists of a narrow slit formed by a pair of knife-edges, capable of being adjusted by means of a screw. The rays of light admitted by this slit are received by

Fig. 255.

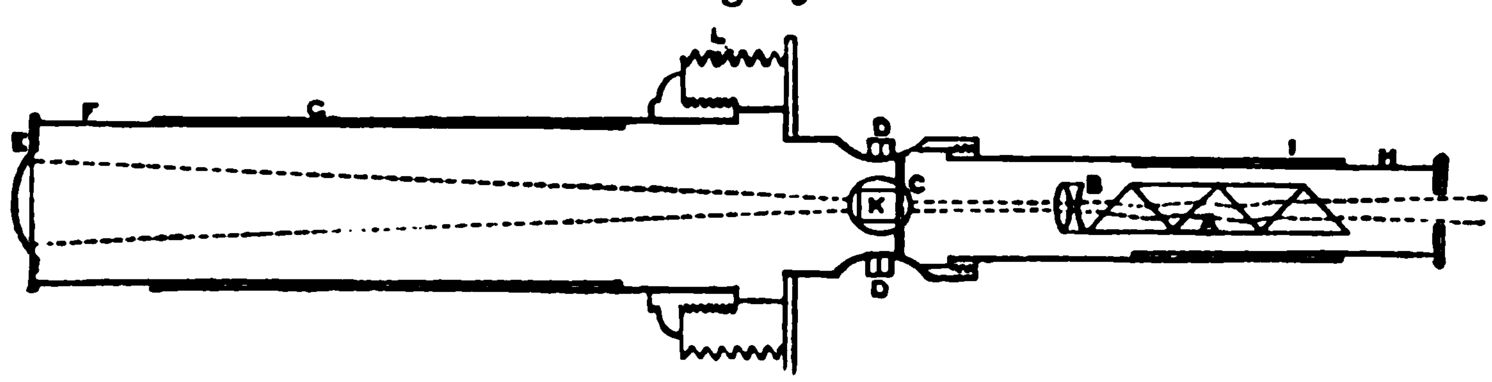
The Astronomical Spectroscope.

a lens placed at its own focal distance from the slit. In passing through this lens the rays are rendered parallel. They are then allowed to fall on a prism of any transparent substance of high dispersive power, by preference on one of extremely dense flint-glass. The spectrum produced by the passage of the light through the prism is then viewed by means of a telescope furnished with a Huyghenian eye-piece of low power. To obtain the best definition, the prism should be placed at the angle of minimum deviation; that is, in such a position that the rays of light in traversing

the prism are equally inclined to its two faces. In the most powerful instruments a number of prisms, sometimes as many as 10 or 11, are arranged in a circle.

A simple form of spectroscope for astronomical purposes, devised by Browning, is represented in Fig. 256. A is a compound direct-vision prism consisting of 5 prisms. B is an achromatic lens which focusses on the slit C by means of a sliding-tube H; both the prisms and the lens are fastened in this tube. K is a small right-angled prism, covering half the slit, by the aid of which light may be seen reflected through the circular aperture in front of it. In this manner a comparison may be made with the spectra of metals or gases. The reflecting prism, with the ring to which it is attached, can be instantly removed, and the whole length of the slit used if desired. D D is a ring milled on the edge; on

Fig. 256.



BROWNING'S STAR SPECTROSCOPE.

turning this round, both edges of the slit recede from each other equally, being acted on by two hollow eccentrics. The lines can thus be increased in breadth without their original centres being displaced—a point of importance. E is a cylindrical lens attached to the tube F, which slides in another tube G. To use the spectroscope on a telescope the adapter needs only to have a thread which shall enable it to be screwed into the draw-tube of the telescope in the place of the ordinary Huyghenian eye-piece.

The draw-tube must then be adjusted so that the slit C comes exactly to the focus of the object-glass. When stars, &c. are about to be observed, this point should be ascertained beforehand by the aid of an image of the Sun, some suitable mark to indicate the focus being made on the draw-tube of the telescope. When this has been once done the tube can be set by this mark, and the spectroscope screwed in at any time without any trouble in adjustment.

If the cylindrical lens be absent the spectrum of a star will be a mere line of light. The cylindrical lens widens this line to such an extent that the lines in the spectrum may be readily discerned. For this purpose the lens must be placed *with its axis at right-angles to the slit*, and the best distance from the slit will be between 3 and 6 inches. The farther the lens is from the slit the broader will be the spectrum, but it should not be removed too far, as the light will be inconveniently diminished. When the spectrum of any celestial object possessed of considerable diameter in the telescope is to be observed, the cylindrical lens may advantageously be removed [o].

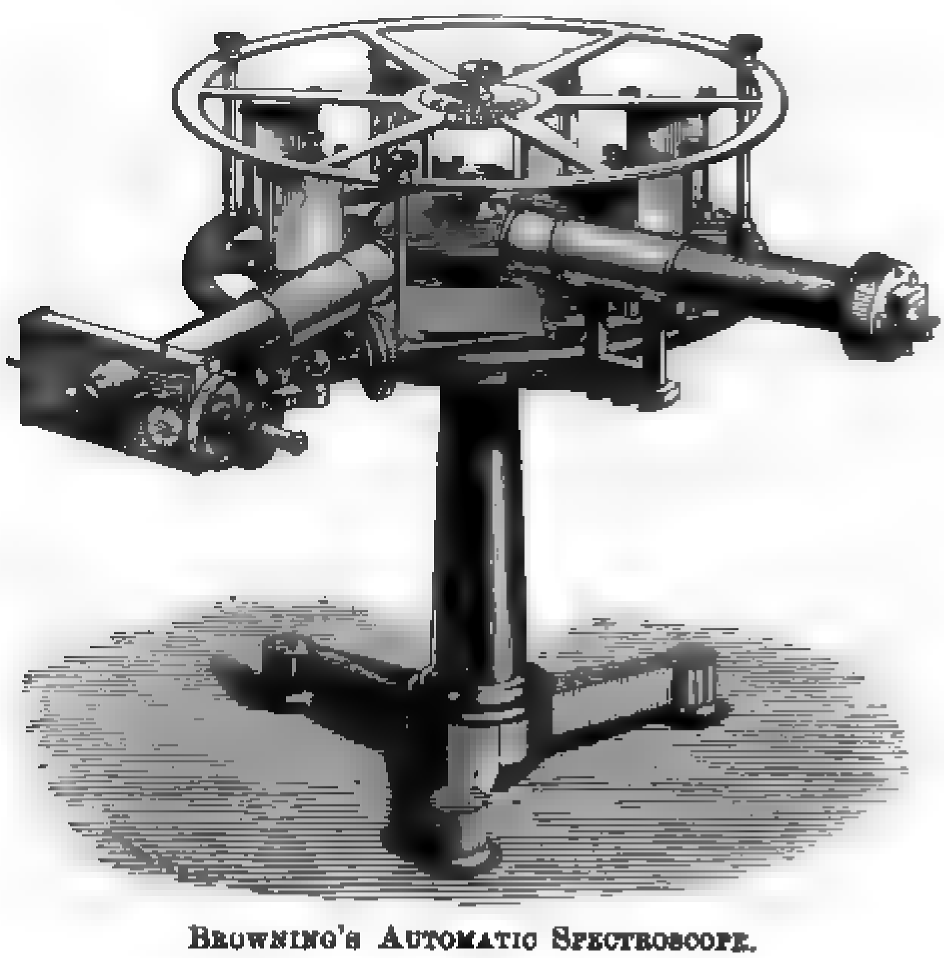
Spectroscopes, which consist of several prisms, are usually adjusted by finding the minimum angle of deviation for the brightest rays situated between the yellow and the green, for each prism which is then permanently secured to its supporting plane. There are, however, two objections to this arrangement. In the first place, only those rays for which the prisms are specially adjusted are seen under the most favourable circumstances, because they only pass through each prism in a line parallel to the base. In the second place, as the last prism is immoveable but the telescope travels in an arc from one end of the spectrum to the other, the object-glass of the telescope receives the full amount of light only when it is directed to the central part of the spectrum; and on the other hand, only a part of the light falls on the object-glass when the telescope is directed to one end of the spectrum, either the red or the violet, as the case may be. It is easy to see that in observing the ends of the spectrum, it is most important that the object-glass should receive the whole of the available light, since it is just these terminal colours that have least brilliancy; this can only be accomplished by the prisms being made adjustable for the minimum of deviation for whatever rays which are under examination. Bunsen and Kirchoff, in their investigations of the solar spectrum, attached the prisms of their compound spectroscope to the ground-plate by means of moveable supports, and altered the position of the prisms for every colour of the spectrum as occasion arose; it is needless to remark that such an arrangement involved much trouble and inconvenience.

[o] *Month. Not.*, vol. xxix. p. 326. June 1869.

This inconvenience is removed in Browning's Automatic Spectroscope (Fig. 257), by so connecting the prisms with each other and the telescope, that on placing the instrument on any particular colour, the prisms, without any special action on the part of the observer, will be simultaneously and automatically adjusted for the minimum of deviation for that colour.

When several prisms are used, the first only is fastened to the ground-plate; the others are connected with each other by hinges at the corners of the triangular metal holders which form the bases. A metal rod, provided with a slit, is attached to the middle of this base, by means of which each prism can move round a

Fig. 257.



BROWNING'S AUTOMATIC SPECTROSCOPE.

central pin common to the whole set. The prisms are arranged in a circle round this pin, which again is fastened to a swallow-tailed moveable bar, about two inches in length, situated under the plate. If, therefore, the central pin be moved, the whole system of prisms moves with it, and the amount of motion communicated to each prism varies in proportion to its distance from the first or stationary prism; if, for instance, the second prism is moved

1°, the third prism moves 2°, the fourth 3°, the fifth 4°, and the sixth 5°, and so on. The tube of the telescope is fastened to a lever which is connected by a hinge with the last prism. At the other end of this lever, or on the carrier of the telescope, works the micrometer screw, by turning which the tube B can be directed upon any part of the spectrum issuing from the sixth prism. This lever is so adjusted that whatever may be the angle to which the telescope is turned, the amount of movement for the last prism shall be twice as great. The rays emerging from the middle of this last prism fall perpendicularly upon the centre of the object-glass of the telescope; the rays issuing from the collimator, and falling upon the first stationary prism, pass through the individual prisms in a line parallel to their base, and arrive finally on their emergence from the last prism, in the direction of the optical axis of the telescope, whether it be directed upon the central or the terminal colours of the spectrum; the object-glass is consequently always filled with light. As the tube is turned towards any colour of the spectrum, the lever sets at the same time all the prisms in motion, in such a manner that each adjusts itself to the minimum angle of deviation. The Automatic Spectroscope is generally recognised to be a great advance in the construction of compound Spectroscopes, by reason of the facilities it affords for good observation.

The most complete treatise on astronomical instruments ever published is undoubtedly Dr. Pearson's *Practical Astronomy*. Though this work is a little out of date, yet the reader may be referred to it for a full account of many of the various matters touched upon in the preceding pages. Of more accessible books none surpasses Loomis's well-known *Practical Astronomy*.

CHAPTER VII.

CELESTIAL PHOTOGRAPHY[a].

Summary of facts connected with the application of Photography to Astronomical purposes.—Description of the apparatus used by Brothers of Manchester.—His method of procedure.

THE credit of having produced the first photograph of a celestial object is generally given to the late G. P. Bond, of Cambridge, U.S.; but it appears from a paper by Professor H. Draper, of New York, published in April 1864, that in the year 1840 his father, Dr. J. W. Draper, was the first who succeeded in photographing the Moon. Dr. Draper states that at the time named (1840) "it was generally supposed the Moon's light contained no actinic rays, and was entirely without effect on the sensitive silver compounds used in Daguerreotyping." With a telescope of 5 inches aperture Dr. Draper obtained pictures on silver plates, and presented them to the Lyceum of Natural History of New York. Daguerre is stated to have made an unsuccessful attempt to photograph the Moon, but I have been unable to ascertain when this experiment was made.

Bond's photographs of the Moon were made in 1850. The telescope used by him was the Cambridge (U.S.) refractor of 15 inches aperture, which gave an image of the Moon at the focus of the object-glass 2 inches in diameter. Daguerreotypes and pictures on glass mounted for the stereoscope were thus obtained, and some of them were shewn at the Great Exhibition of 1851, in London. Bond also proved the advantage to be derived from photographs of double stars, and found that their

[a] For this chapter I am indebted to Mr. A. Brothers, F.R.A.S., of Manchester.

distances could be measured on the plate with results agreeing well with those obtained by direct measurement with the micrometer.

"Between the years 1850 and 1857 we find Secchi in Rome, and Bertch and Arnauld in France, and in England Phillips, Hartnup, Crookes, De La Rue, Fry, and Huggins, appearing as astronomical photographers. To these may be added the name of Dancer, of Manchester, who in February 1852 made some negatives of the Moon with a 4¼-inch object-glass. They were small, but of such excellence that they would bear examination under the microscope with a 3-inch objective, and they are believed to be the first ever taken in this country. Baxendell and Williamson, also of Manchester, were engaged about the same time in producing photographs of the Moon.

"The first detailed account of experiments in celestial photography which I have met with is by Professor Phillips, who read a paper on the subject at the meeting of the British Association at Hull in 1853. In it he says: 'If photography can ever succeed in portraying as much of the Moon as the eye can see and discriminate, we shall be able to leave to future times monuments by which the secular changes of the Moon's physical aspect may be determined. And if this be impracticable—if the utmost success of the photographer should only produce a picture of the larger features of the Moon, this will be a gift of the highest value, since it will be a basis, an accurate and practical foundation of the minuter details, which, with such aid, the artist may confidently sketch.' The pictures of the Moon taken by Professor Phillips were made with a 6¼-inch refractor, by Cooke, of 11-feet focus; this produced a negative of 1¼ inches diameter in 30 seconds. Professor Phillips does not enter very minutely into the photographic part of the subject, but he gives some very useful details of calculations as to what may be expected to be seen in photographs taken with such a splendid instrument as that of Lord Rosse. It is assumed that an image of the Moon may be obtained *direct* of 12 inches diameter, and this, when again magnified sufficiently, would shew 'black bands 12 yards across.' What may be done remains to be seen, but up to the present time these anticipations have not been realised.

"We have next, from the pen of Crookes, a paper communicated to the Royal Society of London, in December 1856, but which

was not read before that Society until February in the following year. Mr. Crookes appears to have obtained good results as early as 1855, and, assisted by a grant from the Donation Fund of the Royal Society, he was enabled to give attention to the subject during the greater part of the year following. The details of the process employed are given with much minuteness. The telescope used was the equatorial refractor at the Liverpool Observatory, of 8 inches aperture and 12½ feet focal length, which produced an image of the Moon 1·35-inch diameter. *The body of a small camera* was fixed in the place of the eye-piece, so that the image of the Moon was received in the usual way on the ground glass. The chemical focus of the object-glass was found to be $\frac{8}{10}$ths of an inch beyond the optical focus, being over-corrected for the actinic rays. Although a good clock movement, driven by water power, was applied to the telescope, it was found necessary to follow the Moon's motion by means of the slow-motion handles attached to the Right Ascension and Declination circles, and this was effected by using an eye-piece, with a power of 200 on the finder, keeping the cross-wires steadily on one spot. With this instrument Hartnup had taken a large number of negatives, but owing to the long exposure required he was not successful; but with more suitable collodion and chemical solutions, and although the temperature of the Observatory was below the freezing-point, Mr. Crookes obtained dense negatives in about 4 seconds. Crookes afterwards enlarged his negatives 20 diameters, and he expresses his opinion that the magnifying should be conducted simultaneously with the photography by having a proper arrangement of lenses, so as to throw an enlarged image of the Moon at once on the collodion plate; and he states that the want of light could be no objection, as an exposure of from 2 to 10 *minutes* would not be 'too severe a tax upon a steady and skilful hand and eye.'

"In an appendix to his paper Mr. Crookes gives some particulars as to the time required to obtain negatives of the Moon with different telescopes, from which it appears that the time varied from 6 minutes to 6 seconds. The different results named must, I conclude, have been caused not so much by the differences in the instruments as in the various processes employed, and in the manipulation. I must observe, also, that it is not stated

whether all the experiments were tried upon the *Full* Moon—a point which would materially affect the time.

"Grubb read a paper on this subject before the Dublin Photographic Society on May 6, 1857. After referring to the fact that he found the actinic focus of his object-glass to be longer than the visual (thus agreeing with Crookes), he states it to be generally understood that in a compound object-glass made as nearly achromatic as possible, the actinic focus is shorter than the visual. The most valuable portion of Grubb's paper is the suggestion for a piece of apparatus to be attached to the part connected with the telescope for holding the dark frame, which he proposes may be so arranged as to follow the Moon's motion in declination; and he gives the following description of a contrivance used by Lord Rosse, and which is suitable for telescopes not equatorially mounted:—'On a flat surface attached to the telescope and parallel to the plane of the image, is attached a sliding plate, the slide being capable of adjustment to the direction of the Moon's path at the time of operating. The slide is actuated by a screw, moved by clockwork and having a governor or regulator of peculiar construction, which acts equally well in all positions. The clockwork being once adjusted requires no change; but the inclination of the slide must be effected by trial for the Moon's path at the time of taking the photograph.' This idea originated with De La Rue: Lord Rosse's share in it arose from his having applied a clock motion to the apparatus.

"The telescope used by Grubb is $12\frac{1}{10}$ inches aperture and 20 feet focus, giving an image $2\frac{1}{10}$ inches diameter in from 10 to 40 seconds.

"The next contribution on this subject is by Mr. Fry, who, in 1857, commenced his experiments on the Moon with an equatorial telescope, the property of Mr. Howell of Brighton. The object-glass of this instrument is $8\frac{1}{2}$ inches diameter and 11 feet focus, and gave an image of the Full Moon in about 3 seconds, but under very favourable circumstances a negative was made in a single second. The size of the image is not stated, but it must have been about $1\frac{1}{4}$ inches diameter. Mr. Fry appears to have removed the eye-piece of the telescope, and in its place fixed a board having a screw adjustment, so that a plate-holder could be moved backwards and forwards on the board (graduated to 10ths of an

inch) for the purpose of finding the actinic focus, which was $\frac{3}{4}$ of an inch beyond the visual. He found that this position of the chemical focus was variable, owing, as he thought, to the varying distance of the Moon from the Earth, but, as suggested by De La Rue, it might arise (?) from the length of the telescope tube having altered through change of temperature.

"In 1857 De La Rue read an important paper before the Royal Astronomical Society [b], from which it appears that the light of the Moon is from 2 to 3 times brighter than that of Jupiter, while its actinic power is only as 6 to 5, or 6 to 4. On Dec. 7, 1857, Jupiter was photographed in 5 seconds and Saturn in 1 minute; and on another occasion the Moon and Saturn were photographed in 15 seconds just after an occultation of the planet.

"The report of the Council of the Royal Astronomical Society for 1858 contains the following remarks:—'A very curious result, since to some extent confirmed by Professor Secchi, has been pointed out by De La Rue, namely, that those portions of the Moon's surface which are illumined by a very oblique ray from the Sun possess so little photogenic power that, although to the eye they appear as bright as other portions of the Moon illumined by a more direct ray, the latter will produce the effect, called by photographers, solarisation, before the former (the obliquely-illumined portions) can produce the faintest image.' And the report also suggests that the Moon may have a comparatively dense atmosphere, and that there may be vegetation on those parts called seas.

"At the meeting of the British Association at Aberdeen, in 1859, De La Rue read a very valuable paper on Celestial Photography. An abstract of it was published at the time in the *British Journal of Photography*, and in August and September of the following year further details of this gentleman's method of working were given in the same Journal. The processes and machinery employed are so minutely described that it is unnecessary here to say more than that he commenced his experiments about the end of 1852, and that he used a reflecting telescope of his own manufacture of 13 inches aperture and 10 feet focal length, which gives a negative of the Moon averaging about $1\frac{1}{10}$th of an inch in diameter. The

[b] See *Month. Not.*, vol. xviii. pp. 16 and 54. Nov. and Dec. 1857.

photographs were at first taken at the side of the tube after the image had been twice reflected. This was afterwards altered so as to allow the image to pass direct to the collodion plate, but the advantage gained by this method was not so satisfactory as was expected. In taking pictures at the side of the tube, *a small camera box* was fixed in the place of the eye-piece, and at the back a small compound microscope was attached, so that the edge of a broad wire was always kept in contact with one of the craters on the Moon's surface, the image being seen through the collodion film at the same time with the wire in the focus of the microscope. This ingenious contrivance, in the absence of a driving-clock, was found to be very effectual, and some very sharp and beautiful negatives were thus obtained. De La Rue afterwards applied a clockwork motion to the telescope, and his negatives taken with the same instrument are as yet the best ever obtained in this country.

"The advantage of the reflecting over the refracting telescope is very great, owing to the coincidence of the visual and actinic foci; but it will presently appear that the refractor can be made to equal, if not excel, the work of the reflector.

"De La Rue's paper (as published in the Report of the British Association) contains some extremely interesting particulars as to the mode of obtaining stereoscopic pictures of the Moon, and diagrams are given shewing the effects of the Moon's libration. The most beautiful stereoscopic prints of the Moon are those by De La Rue. Mr. Fry also was very successful in this branch of the art.

"In this brief history of the subject of celestial photography I have not referred to anything which has been done in making photographs of the solar spots, but the matter must not be altogether passed over. The first step in this direction appears to have been taken in France in 1845, by Fizeau and Foucault; but it is chiefly due to the efforts of De La Rue that so much useful work has been done in heliography. In 1860 he and his staff of assistants performed one of the greatest feats yet recorded in this branch of the art of photography, for they succeeded in obtaining several beautiful negatives of the various phenomena seen only during total eclipses of the Sun, and 2 negatives were obtained during the totality. One question of much interest to

astronomers was determined by this great experiment. The red prominences or flames generally seen as issuing from the edge of the Moon were proved to belong to the Sun. Photographs of the Sun are taken daily when the weather is favourable at the Kew Observatory, and also by Professor Selwyn, at Ely. With the Kew Photo-heliograph pictures of the Sun, spots have been made on the scale of 3 feet for the Sun's diameter. Much, however, remains to be done. The light of the Sun is so much in excess of that which is required to obtain a collodion picture, that the loss of light consequent on the necessary interposition of lenses and the distance of the plate from the instrument can present no objection; and for these reasons I have very little doubt that, with apparatus suitably arranged, photographs of spots and groups of spots will be obtained of very much larger dimensions than any yet taken.

"The *Quarterly Journal of Science* for April 1864 contains the next important paper on Celestial Photography. It is by Dr. Henry Draper, one of the Professors at the New York University. On his return to America—after paying a visit to Parsonstown, where he had the advantage not only of making some observations with Lord Rosse's large reflector, but also of seeing the method there pursued in grinding and polishing mirrors—stimulated by what he had seen, he determined to build an Observatory, and to construct an instrument to be devoted solely to celestial photography. The speculum used by Dr. Draper is 15½ inches in diameter, and 12½ feet focal length; but this was afterwards superseded by one of glass on Foucault's principle. The great labour involved in a work of this character may be judged of by the fact that Dr. Draper ground and polished more than 100 mirrors, varying in diameter from 19 inches to ¼ inch; but he appears at last to have secured a good instrument. The chief points to be noticed in this article are, that instead of driving the telescope in the usual way by means of a clock, the frame carrying the glass plate was made to move on the plan previously referred to. Instead of clockwork to effect this motion, an instrument called a 'clepsydra' was used. It has a weight on a piston rod, which fits into a cylinder filled with water, which is allowed to escape by means of a stop-cock, and can be regulated with great exactness, so as to follow the object. The large

number of 1500 negatives is stated to have been taken at this Observatory, some of which would bear magnifying 25 diameters (the paper says *times*, but I assume this to be an error, as a negative must be very bad if it will not bear more than 5 diameters, or 25 times). As the average size of the negatives was $1\frac{4}{10}$ inch, an increase of 25 diameters would give an image of the Moon nearly 3 feet in diameter. I have not seen the prints from these negatives, and have never heard anything about the quality of the work produced by this telescope; but it may be stated that Dr. Draper writes as if the negatives were of the best quality, and encourages others to follow his example.

"Nearly a quarter of a century has elapsed since the Moon was first photographed in America, and a great deal has been since done on that side of the Atlantic. To an American we are indebted for the best pictures of our satellite yet produced, and it is difficult to conceive that anything superior can ever be obtained; and yet with the fact before us that De La Rue's are better than any others taken in this country, so it may prove that even the marvellous pictures of Mr. Rutherford may be surpassed.

"Mr. Rutherford appears, from a paper in Silliman's *American Journal of Science* for May 1865, to have begun his work in lunar photography in 1858 with an equatorial of $11\frac{1}{4}$ inches aperture and 14 feet focal length, and corrected in the usual way for the visual focus only. The actinic focus was found to be $\frac{7}{10}$ths of an inch longer than the visual. The instrument gave pictures of the Moon, and of the stars down to the 5th magnitude, which were satisfactory when compared with what had previously been done, but not sufficiently so to satisfy Mr. Rutherford, who, after trying to correct for the photographic ray by working with combinations of lenses inserted in the tube between the object-glass and sensitive plate, commenced some experiments in 1861 with a silvered mirror of 13 inches diameter, which was mounted in a frame and strapped to the tube of the refractor. Mr. Rutherford enumerates several objections to the reflector for this kind of work, but admits the advantage of the coincidence of foci. The reflector was abandoned for a refractor specially constructed of the same size as the first one, and nearly of the same focal length, but corrected only for the chemical rays. This glass was completed

in December 1864, but it was not until March 6 of the following year that a sufficiently clear atmosphere occurred, and on that night the negative was taken from which the prints were made.

"I have entered somewhat minutely into particulars of what has been done in this branch of art, in order that we may have before us a kind of summary or index of the work done up to the present time, so that those who desire further information may at once refer to the authorities quoted. It may be asked why it was thought necessary to draw up this abstract, as De La Rue and others have said almost all that is necessary to enable any one to take up the subject and to pursue it successfully.

"It is true that there are very elaborate papers, and from their perusal I have derived much useful information; but at the same time it must be confessed their very elaborateness deterred me, for a long time after I possessed the necessary apparatus, from commencing the experiments which have since afforded me so much enjoyment.

"Every writer on this subject speaks of the difficulties encountered from optical, instrumental, and atmospheric causes; and to this may be attributed the fact that so few of our amateur astronomers give their attention to this subject. Another reason may be that comparatively few of those who possess telescopes have the necessary photographic knowledge; but surely some friend having this knowledge might be found who would be willing to spare a few hours occasionally to assist in taking negatives of the stars, planets, or of the Moon. The reason, then, why this subject is brought forward now is that it is believed that the apparatus which I use is, in some particulars, more simple than any heretofore described, and as it can be employed with any kind of telescope, a greater number of amateurs than are now engaged in it may be induced to follow this branch of photography.

"It will have been noticed that when particulars of the apparatus have been given the writer has spoken of a *small camera*, which has been fixed at the eye-piece end of the telescope. Of the manner in which this was effected I have seen no description, and as no camera box is now required I need not enter into any supposition on the subject. Before deciding what was necessary to be done, it occurred to me that the telescope tube itself would form the camera, and all that was required was the means of fixing the

dark frame or plate-holder. If the telescope be pointed to the Moon, the eye-piece removed, and a piece of ground glass held between the eye and the aperture, the image will be seen on the glass, and we then require the means of holding the sensitive plate steadily near the same place. All that is needed is a brass tube about 4 or 5 inches long, of a size exactly fitting the tube of the telescope in the place of the eye-piece. In some cases the sliding tube of the eye-piece may be unscrewed and used for this purpose. At one end of this tube a thread is cut and is made to screw into a piece of metal plate (in the centre of which is a circular aperture of the same size as the tube) of the same dimensions as the dark frame. Attached to the plate-holder are clips accurately fitting the brass plate, but in such a way that the frame will easily slide off and on without disturbing the telescope. This is all the additional apparatus required to enable photographs of the Moon or any other celestial object to be made. A separate frame for the ground glass is not necessary; it must be cut to fit the dark frame, and while in use can be held by slight springs fixed inside the frame at the sides.

"The accompanying woodcuts shew the arrangement of the apparatus when in its place for taking a negative, and render further description unnecessary. The method for ascertaining the actinic focus may be stated in a few words. With the rack motion adjust the focus for distinct vision on the ground glass, and then mark the tube *d*, and also the sliding part of the telescope. Although it is very unlikely to be of the slightest use, unless taken with a reflecting telescope, a picture may now be taken: it will at least serve to give some idea of the proper exposure. If the chemical and visual foci are not coincident, the image will have a blurred appearance. Before exposing the next plate, turn the adjusting screw so as to lengthen the tube about $\frac{1}{16}$th of an inch, and so proceed until, by the greater distinctness of the image, it is seen that the chemical focus is found. At every change of the focus a slight mark should be made on the tube, and when the true focus is satisfactorily determined the marks should be made distinctly visible; and in all future experiments with the same instrument the focus will be always at or very near the same place. Should it be found that the indistinctness increases, it will of course be necessary to try in the other direction.

"The appearances arising from atmospheric disturbances are very much the same as when the object is out of focus: experience alone will enable the operator to determine from which cause the defect proceeds.

Fig. 258.

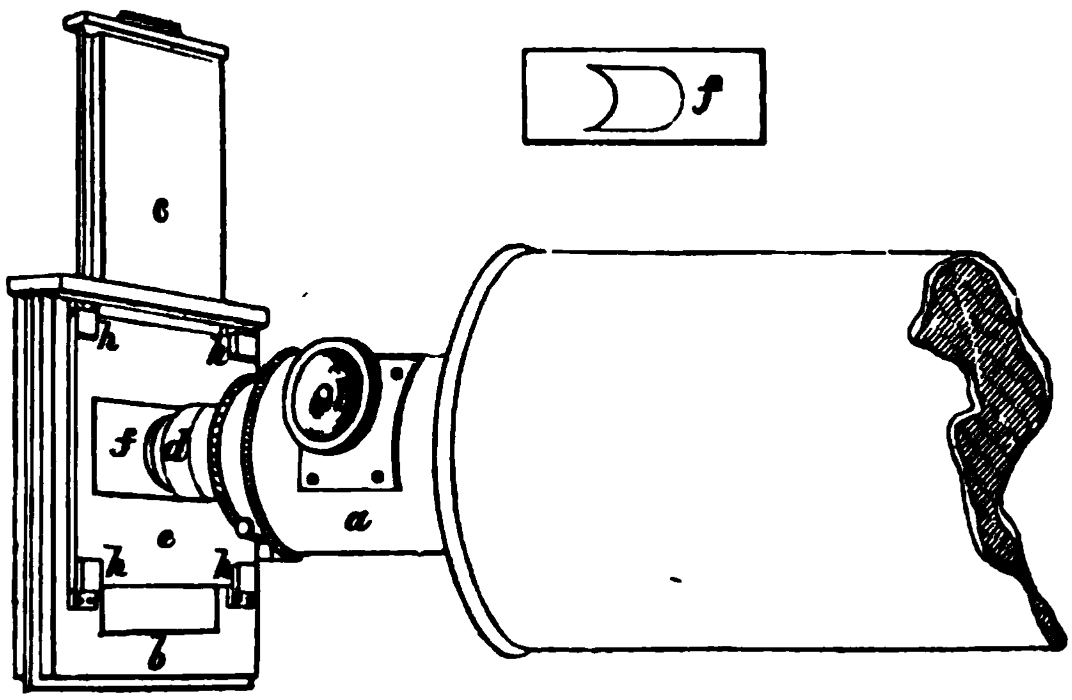


Fig. 259.

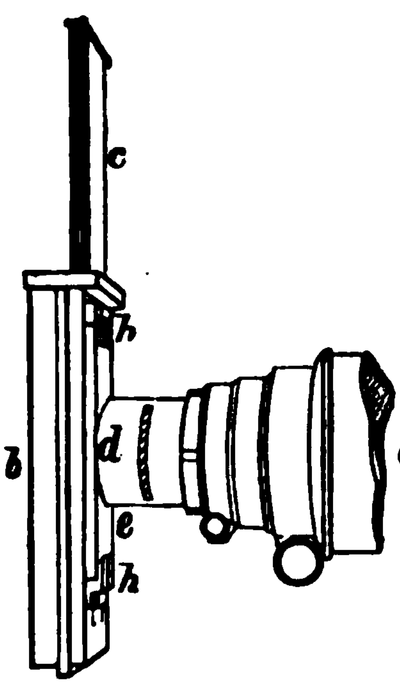
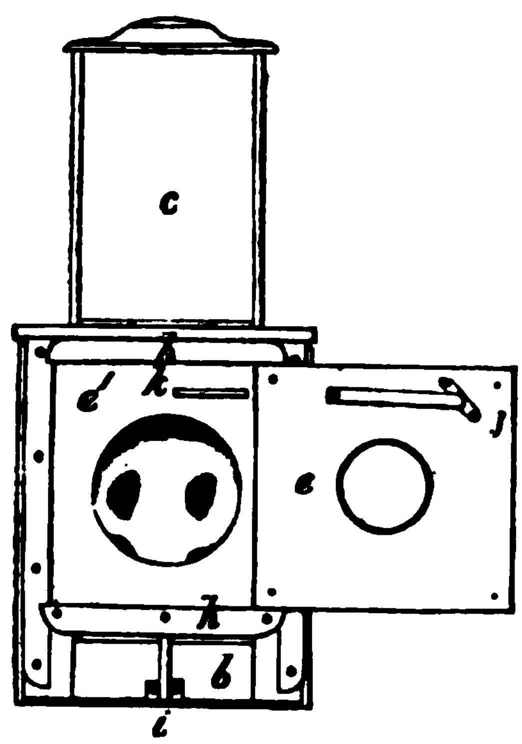


Fig. 260.



APPARATUS FOR TAKING ASTRONOMICAL PHOTOGRAPHS.

a Draw-tube of telescope. *b* Dark frame. *c* Slide. *d* Brass tube sliding into place of eye-piece. *e* Outer metal plate screwed to *d*. *é* Inner metal plate. *f* Diaphragm. *h* Clips to hold plate *e*. *i* Spring to hold frame in first position. *k* Groove in the plate *e* in which the spring-pin *j* slides.

"It is assumed that the telescope is provided with a driving-clock: when such is the case, every care should be taken that all the parts are clean, and, when necessary, oiled or greased, so that the motions may be as smooth as possible.

"In photographs of the Moon in the phases prior to and after the full, the side opposite to the Sun is always too light, or 'burnt up,' while those parts near the terminator are often so dark that only the tops of the craters and peaks are visible, although in the telescope a clear and bright image can be seen. The cause of this must be that the exposure, if continued long enough to bring out all the eye can see on the darker side, would entirely obliterate the details on the brightly-illuminated portions of the Moon's surface. De La Rue's suggestion as to the reason why the dark side of the Moon has so little actinic effect, has been already referred to. I would suggest that, as the light of the Full Moon is 100,000 times weaker than that of the Sun, the *twilight* on the Moon's surface must be very much less, and consequently the actinic effect of the light is lessened in the same way as at a corresponding time on the Earth [c].

"The question, then, of photographing the terminator is only one of time, and in order to remedy the defect spoken of to some extent, I have used a diaphragm such as is shewn in the drawing. In the tube *e*, openings are made on opposite sides, wide enough to admit the diaphragms to be used without touching the tube. The diaphragm must be of the proper length and width to shut off the Moon's light until the plate is ready for exposure. The shape of the diaphragm will suggest which form should be used, according to the Moon's age. The exposure should be made with the full aperture for as many seconds as previous experiments have proved to be necessary for the bright side, and the diaphragm then gently moved and kept in motion, gradually approaching the darkened side. By this means the exposure may be regulated, and the great differences in the light and dark sides of the Moon may be modified.

"As to the processes employed each experimenter must adopt the one which in his hands gives the best result. It seldom happens that two operators can produce the same effects with, *apparently*, the same chemicals. Experience has shewn me that

[c] In the absence of an atmosphere on the Moon, there can of course be no *twilight* such as we have on the Earth. I mean to say, that on those parts of the Moon enlightened only by the oblique rays of the Sun, the light is so diminished that the actinic effect is lessened as it is on the Earth shortly before sunset and during twilight, when it is well known that a much longer time is required to obtain a photograph.

the ordinary patent plate glass (carefully selected, so as to be free from scratches and other defects) is preferable to the white patent plate, for after a time the surface of the latter becomes covered with a kind of dew, or 'sweat' as it is termed, owing to the decomposition of some of the salts used in the manufacture. The collodion used was made for me by Huggon and Co. of Leeds; it is very quick, free from structure, and suitable for iron development. I prefer to develope with an iron solution, using only sufficient to cover the plate; and with this developer and collodion, when the plate has been properly exposed, a negative can be obtained which will not require intensifying afterwards. Not having had sufficient experience with pyrogallic acid, I cannot speak with confidence as to any advantage it may possess in giving fine texture to the negative. With the bath and collodion exactly in the proper state, there is no doubt that with this acid, negatives may be made as quickly as with iron; but it is extremely difficult to have everything constantly in the best working order. Unless the greatest attention be given to this matter, the time of exposure is so much increased that iron, for this reason, must have the preference.

"Upon the character of the image after development entirely depends the value of the enlargement to be made from it, and in this direction there is much room for improvement. Even in the best negatives yet made defects from this cause are very apparent. The microscopic photographs by Dancer have the finest texture, and will consequently bear greater magnifying than any other photographs I have ever seen, but the process by which they are made is not published.

"The weather in this country is so very uncertain, and success in this branch of photography is so entirely dependent on the state of the atmosphere, that it is necessary to be always prepared to take advantage of a favourable night. I have a small cupboard placed in a convenient part of my house where there is a supply of water, and the temperature is always much above the air outside. This cupboard is just large enough to hold a small glass bath fixed at the proper angle ready for use, also the bottles for collodion, bath, developing and fixing solutions, and other little requisites. This arrangement is so convenient that when there is a prospect of getting a negative I can set the telescope, prepare the plate,

and take a negative in less than 10^m. But when there is a chance of two or three hours' work an assistant is desirable, as the best results can only be obtained when one's attention is chiefly devoted to the careful adjustment of the apparatus connected with the telescope.

"The convenience of the plan adopted may be judged of by the fact that on the evening of the partial eclipse of the Moon, Oct. 4, 1865, in four hours I succeeded, with the help of two assistants, in taking no less than 20 negatives, and the telescope was several times disturbed to oblige friends who desired to see the progress of the eclipse through the instrument; but the apparatus was quickly re-adjusted, although possibly in some cases with a slight loss of definition in the negative through haste. It may be interesting to refer to the fact that while No. 15 of the series was taken the telescope was at rest. The clock had been disconnected for re-adjustment, and it was forgotten when the plate was ready for exposure: consequently the Moon had moved partly off the plate, and the negative shews a portion only; but the exposure was so short that the eye fails to detect any difference between the sharpness of this and of the others, which were all taken when the clock had been watched and carefully regulated for the Moon's motion. This fact is, I think, of some interest, as it shews that about the time of Full Moon, when the light is of the greatest intensity, pictures may be made with telescopes not equatorially mounted.

"My telescope is a refractor of 5 inches aperture and 6 feet focal length, giving an image of the Moon averaging about $\frac{11}{18}$ of an inch in diameter. The actinic focus is about $\frac{1}{10}$th of an inch longer than the visual; but this varies. The object-glass is a Munich one, and is mounted by Dancer on the English plan with double polar axis. The hour circle is 26 inches in diameter, and is used also as the driving-wheel, having teeth cut in the edge in which a screw works, and by which it is connected with the driving-clock by a rod, and can be instantly disconnected by means of a cam. The object-glass is an excellent one, and the mounting is everything that canbe desired.

"The negative taken direct in the telescope is but one step towards what we require—that is, the enlarged copy on paper. From the small negative a positive on glass must be made, say

of twice or three times the diameter of the original. It will be quite unnecessary here to explain how the enlargement is to be made, but I may remark that the negative should be placed with the film side towards the copying lens, and the resulting positive copy must also be placed in the same way. The enlarged copy or negative will then give the true telescopic appearance of the Moon. In the print of the Full Moon by Rutherford a mistake has been made, arising from the negative or positive copy having been placed the wrong way, and consequently the Moon looks as if it had been photographed from the opposite side. The print is a very beautiful one in other particulars, but entirely worthless as a picture of the Moon, as the eye can never see it as there represented.

"I have sometimes taken two negatives on the same plate. It will be seen in fig. 259 that the dark slide is not quite central with the telescope, so that by reversing the plate after one exposure a second picture can be taken. In photographing the planets, De La Rue has allowed the object to move on for a few seconds, the telescope meanwhile being at rest, and thus four or five negatives can be taken in a very short time on the same plate. It has occurred to me that by having a suitable frame, and by having in place of four clips such as *h* [fig. 258] a kind of groove at top and bottom and at the sides of the frame, so that after taking the first negative the light might be shut off by moving the plate about an inch, at least 4 negatives might be taken on the same plate. The advantages of this plan are, that different exposures might be tried and the development continued for the one or two which promised the best results. This method would effect a great saving of time, which on a fine night is of much importance.

"A frame adapted for taking four negatives on the same plate is shewn in fig. 259. With this instrument 100 negatives of the Moon have been taken in 4 hours, and when the sky is continuously clear there is no difficulty whatever in proceeding at the same rate, and without the least hurry or confusion. On the occasion of a total eclipse of the Sun, apparatus of this kind would be found to be of the greatest service. Supposing the total phase to last 3 minutes, and the exposure requisite to produce a negative 15 seconds, 12 negatives could be made; and if the manipulation

of the plates had been carefully performed, the whole series might be as good as if 2 or 3 only had been made.

"With the Barlow lens I have made some negatives which have shewn that when the same care has been taken to find the actinic focus negatives of a much larger size may be made, and in a very short time. The image was increased from $\frac{11}{16}$ths to $1\frac{1}{4}$ inches, and the time of exposure at Full Moon was 2 seconds. The fittings of the lens are so arranged that three different-sized negatives may be taken."

CHAPTER VIII.

PRACTICAL HINTS ON THE CONDUCT OF ASTRONOMICAL OBSERVATIONS.

THE present chapter must be regarded as made up of waifs and strays collected from a great variety of sources, and thrown together without much order or method.

1. ON THE CHOICE OF INSTRUMENTS AND THEIR ACCESSORIES.

Always prefer a refracting to a reflecting telescope. Refractors are far more manageable than reflectors, and less liable to suffer from neglect or inexperience, though it must be admitted that, aperture for aperture, the latter are much cheaper [a].

Though neatness in the metal-work is highly desirable, yet be careful not to think too much of it, for there may be an excellent outward appearance with very slight internal value. The ultimate performance depends not on the polish of your tubes, but on the accuracy of your lenses, as regards their figure, centering, &c. Air-bubbles, sand-holes, *striæ*, scratches, are no doubt undesirable in their way, but do not be troubled too much about them; they are not absolutely inconsistent with good definition; they merely obstruct an infinitesimal amount of light. Remarks on testing object-glasses have already been made in a former chapter.

The centering of the lenses should be properly performed by the maker; if, however, he has not attended to this, it is best, unless the inconvenience is very serious, to put up with the evil. An inexperienced hand often not only makes matters worse, but commits irreparable damage.

[a] An interesting paper describing Comparison Experiments by C. E. Burton, will be found in *Ast. Reg.*, vol. x. p. 289. Dec. 1872.

A dew-cap is always desirable, though not invariably supplied to small telescopes. At night it is needed to protect the object-glass from the aqueous vapour floating about in the air; and in the day-time it serves to lessen the light reflected into the tube by the metal ring in which the object-glass is mounted.

Every telescope of and beyond 2½ inches aperture should have a finder, however small; its use saves an incalculable deal of trouble, and prevents much loss of time—an important matter in a climate where clear and astronomically-good skies are rather rare. Especially will the observer, who employs a telescope not equatorially mounted, discover the usefulness of this inexpensive little accessory after a few nights' trial with and without the same. A finder too is very convenient in working with a transit instrument, though not ordinarily applied thereto. Its employment tends to guard the observer against surprises, and against the consequences of error in the setting of his circle.

As regards powers—the common idea generally encourages a number that is excessive. Without attempting to lay down any stringent rules[b], the following lists (based for the most part on giving one eye-piece for each inch of aperture) are offered in the belief that most amateurs will find them amply adequate:—

Apertures of

2 in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.
15	20	25	30	35	40	50	60	75
45	55	65	85	85	95	110	130	150
100	110	140	170	160	170	200	200	240
	200	300	280	250	260	300	300	350
			420	360	390	410	410	470
				500	500	530	530	590
					680	660	670	710
						800	810	840
							950	980
								1140

The highest powers must be reserved for the examination of close double stars on peculiarly good nights, and with clockwork

[b] Pogson has pointed out that for an optical reason depending on the average diameter of the pupil of the eye, the lowest available power is 5 times the aperture of the telescope in inches.

motion. Burnham recommends all eye-pieces being fitted so as to be "self-focussing." That is to say that by metal stops it should be arranged that directly they are pushed "home" they should be in focus. His procedure is as follows:—Select a good night and a close and difficult double star; focus very carefully your highest power. Then replace it by the next lower power, pushing this into the draw-tube and bringing it to focus *without moving the draw-tube:* make a mark on the eye-piece at the draw-tube, and so with each eye-piece in succession. Fit on to each a narrow ring of tin or other metal, leaving the ring somewhat wider at 2 opposite points than the distance between the original shoulder of the eye-piece and the mark. File down these projections gradually till the point of clearest vision is reached. A few trials will suffice. It is true that different conditions of air and eye affect the focus of eye-pieces, but Burnham asserts that the differences are less, really, than is usually supposed, and that a trifling adjustment of the draw-tube for the improved focus of one eye-piece will carry with it the necessary rectification for all of a series prepared as above, if the fitting has been carefully performed.

The highest power which a good refractor can fairly be expected to carry under the most favourable circumstances may be ascertained roughly by *multiplying its aperture in inches by* 100. Example:—What is the highest power that can fairly be used on a telescope of $4\frac{1}{8}$ inches aperture? Here $4\frac{1}{8} \times 100 = 412$. It need hardly be said that this rule must be accepted subject to reservations. Rarely in England will it be possible to use so high a power as the rule suggests; occasionally, however, a higher power may be indulged in.

As regards the limits of vision of achromatic telescopes, the following rule will be found nearly correct for Argelander's scale of magnitudes. *Multiply log. of aperture in inches by* 5 *and add* 9·2 *to the result.* Example:—What is the smallest star visible in a telescope of 4 inches aperture?

Log. 4	=	0·6020600
		5
		3·0103000
Add		9·2
		12·21

Therefore a telescope of 4 inches aperture may be expected to show stars of mag. 12, but nothing so small as mag. 13 of Argelander's scale.

Another form of this problem has been presented to me in MS. by Mr. N. Pogson, especially for this work. His rule is:—

Determine by trial the smallest star (Argelander or Radcliffe) which you can see with an aperture of 1 *inch. Then the limit of vision for any other aperture will be:—*

One-inch limit $+ 5 \times$ *log. aperture.* He remarks that "The limit for 1 inch will differ less than people imagine, averaging about $9\frac{1}{4}$."

For 4 inches of aperture we have the following figures:—

$9{\cdot}25 + 5 \times 0{\cdot}602 = 12{\cdot}26$. The result accords very well with the one given above.

The intending observer would do well to allot a portion of his funds to the purchase of an equatorial stand (coupled with clock-work to drive the telescope with, if the aperture of his glass exceeds 4 inches), in preference to concentrating his means on a larger glass imperfectly mounted; for without these 2 aids his work will be very tedious, particularly if he proposes to study faint objects of any kind.

The parallel-wire micrometer is of course the "arm of precision," but for most amateurs a reticulated micrometer will suffice: it should be applied to an eye-piece of rather low power, say, intermediate between the 1st and 2nd of the "battery," as it can there be made to do double duty to some extent. The 1st ordinary power should have as large a field as possible, that it may be used for sweeping for comets.

As regards cleaning lenses of all kinds, the first and most important rule is, never to meddle with them except in cases of the most pressing and obvious necessity. Optical glass requires careful and delicate treatment, and a few specks of dust are of much less moment than ugly scratches, never afterwards to be removed. A soft camel's-hair brush will be found of much use for removing coarse particles of dust from lenses; then the application of the brush may be followed by the cautious use of a piece of very fine and clean chamois leather, or of a soft silk handkerchief: better, however, than either of these is an old but fine cambric handkerchief. Everything used for wiping or rubbing lenses should be

kept wrapped up in paper or in a little box when not in use, and the wiping or rubbing should be performed very gently. A drop or two of spirits of wine on chemically clean cotton wool will be found very useful for removing refractory stains, but the careful observer will never allow any refractory stains to get on his glasses.

The brass-work of a telescope should be dusted from time to time: if it gets a little dull or dirty, no better application can be found than a piece of chamois leather, moderately moistened with sweet oil.

When out of use for more than 2 or 3 days, it will be found advantageous to keep the entire instrument, stand included, covered with an old sheet or table-cloth, *except in damp weather.*

Something should be said on the management of Reflectors, and on preserving the silvered surfaces of the mirrors thereof[c].

Several methods, depending on the employment of deliquescent chemical substances, have been proposed for preventing silvered surfaces from becoming tarnished. All are troublesome, and sometimes they do more harm than good. Practically, it is quite sufficient that the mirror, when not in use, should be protected by a tightly-fitting cover[d].

It is a good plan to envelope the telescope, when not in use, in a wrapper made of American leather cloth. Should the mirror be left in its place, such a covering shelters the mirror, and under any circumstances, it will keep dust out of the instrument. If, in spite of precautions, a deposit of moisture should have taken place on the mirror, or rain have fallen on it, the mirror should be gently warmed in front of a fire, and kept there until the moisture has evaporated and the surface become dry. If stains should be left, they may be removed by polishing in small circular strokes with a rouged leather pad, first letting the mirror cool. The pad should be warmed to dry it, but allowed to get cool before being used.

However much the surface of the mirror may seem to have got out of condition, if these instructions be followed its original

[c] These remarks have been inspired by Mr. Browning, who is a practised observer as well as a good optician.

[d] The larger sizes of reflectors are often made with a door in the lower part of the tube, for the purpose of covering and uncovering the mirror without removing it from the tube.

state of polish may be restored to it, but *if the moistened surface be rubbed before it has become perfectly dry, the silvering will be damaged.*

As a general rule the best thing to be done, is to *let the silver coating alone as much as possible.* There is no necessity to envelope the whole telescope tightly, merely because it is left in the open air; indeed, it is better not to do so. The laws of radiation are such that more likely than not the instrument will be injured by too much cosseting. A loose-fitting wrapper (water-proof of course), which protects it well from the direct impact of rain, is all that is required.

It is necessary also to have and to use a small brass cover, which can be slipped over the diagonal mirror without removing it, or altering its adjustments.

Silvered surfaces should not be subjected to any rubbing oftener than once in six months at the utmost, and if handled with reasonable care, should last without renewal for 3 or 4 years.

A mirror should not be taken from the cold air into a warm room; or, when this cannot be avoided, the cover should be placed on the mirror while it is in the open air, or in a cold place, and the mirror and cell should be put in a box with a well-fitting lid, before it is removed to the warm apartment. This will prevent a deposition of moisture.

2. On the choice of Stands, &c.

This is little else than a financial matter, but it is a very important one. Beyond doubt more may be got out of a small instrument on a good stand than out of a large instrument on a bad one. A good stand means not simply a steady but a manageable one, and a manageable stand means an equatorial one. Every telescope of and beyond 3 inches aperture ought to be equatorially mounted; and, after all, the measure of the usefulness of a telescope is the work that can be done with it much more than the inches of its aperture. Objects invisible to the naked eye—*i. e.* the majority of the objects in the starry heavens—can, as a rule, only be found after much labour and loss of time by an observer who is unprovided with an equatorial mounting: the waste of energy thus engendered trenches materially on his available opportunities and sense of pleasure. Where the site can be had, an iron pillar out of doors is the best substitute, and

the metal-work forming the equatorial, which need not be very fine or elaborate, can readily be protected from the weather, the telescope itself being kept in the house and carried out when wanted. In other cases a wooden tripod may be used; these may now be had solid enough to be steady without being too heavy to be portable. The circles attached to the hour and declination axes need not be too finely graduated, if, as is commonly the case, they are merely intended to be used for finding objects, and the coarser the graduation the less expensive they are.

If you are so circumstanced as to be able to have your stand a fixture, it is here proposed to recommend that it be covered over by an observatory. The name is formidable, but a carpenter's shop and £20 or so will provide you with one for a small equatorial; and the comfort and protection afforded to yourself and your instrument will in a very few weeks be demonstrated. Finally, with an equatorial mounting, and an observatory to cover it, you should have clockwork to drive it. It must candidly be confessed that this is an article of luxury, but still for high powers it is very desirable, and for micrometrical measurements and pencil-and-paper delineations it is virtually indispensable.

For a large telescope a specially constructed observing-chair is needful, but in working with a small one I have found that a dwarf pair of carpenter's steps, an ordinary music-stool, and a foot-stool suffice to give all the change of position usually requisite.

Dawes contrived[e] an observing-chair, for which he claimed the merit of convenience and simplicity combined with comparative inexpensiveness. Fig. 261 will enable its construction to be understood. The angle of the slanting upper part of the frame is about 30°. In the left-hand slanting-timber there are a number of notches, and attached to the sliding body or chair is a stout catch, which falls into the notches one after another as the chair is raised. When the catch is lifted by the observer's left hand the chair will descend.

The back of the chair is supported by an iron quadrant toothed on the under side; and a catch is forced by a spring into the teeth as the back is raised, to support it at any convenient elevation. The catch can be pushed out of the teeth by the observer reaching behind him with one hand, while he diminishes the slope of the

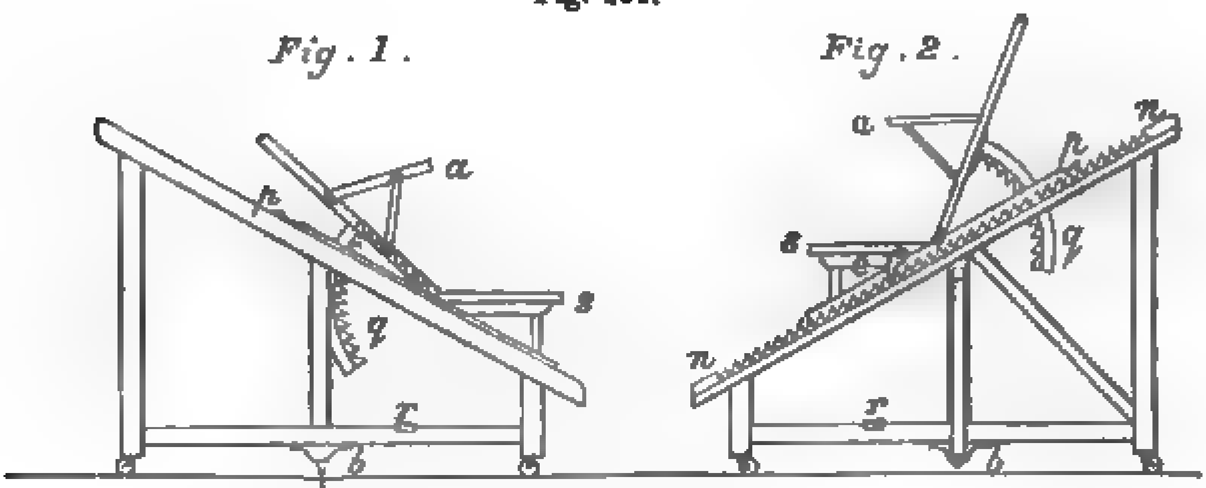
[e] *Month. Not.*, vol. xxviii. p. 9. Nov. 1867.

back with the other hand. On the right-hand side of the chair is an arm, which can be adjusted at pleasure to support the observer's elbow, and aid in keeping the hand steady in the management, for instance, of a micrometer.

The angle which the slanting frame makes with the horizon is so arranged that when the seat is raised nearly to the top, the observer's eye may be about the same height from the floor as it would be if he were standing. Of course the angle may be varied with regard to the distance of the pillar of the equatorial from the wall of the room, and to the height of the declination axis above the floor.

On the left side of the frame, attached to the upright timber strut near the middle of the frame, is a long stout bolt with a sharp

Fig. 261.



Dawes's Observing Chair.

point, so arranged as to be free of the floor when up, and to pierce the floor when pushed down. This enables the observer to *cast anchor*, as it were, to the detriment, however, of the floor.

The following is a more particular description of the several parts:—

Fig. 1. *Right side.*

a. Moveable arm, for supporting the observer's elbow.

b. Bolt, for anchoring. Sharp point *pushed into floor.*

p. Pin, by pressing which the spring is pushed out of the teeth of the *quadrant q.*

r. Rail across the lower frame for supporting the feet thereof. May be removed if in the way of the *quadrant q.*

Fig. 2. *Left side.*

a. See Fig. 1.

b. Bolt, as fixed on the middle upright timber; represented as *drawn up.*

c. Catch, which falls into the notches (*n n*) in the slanting timber, and supports the seat (*s*).

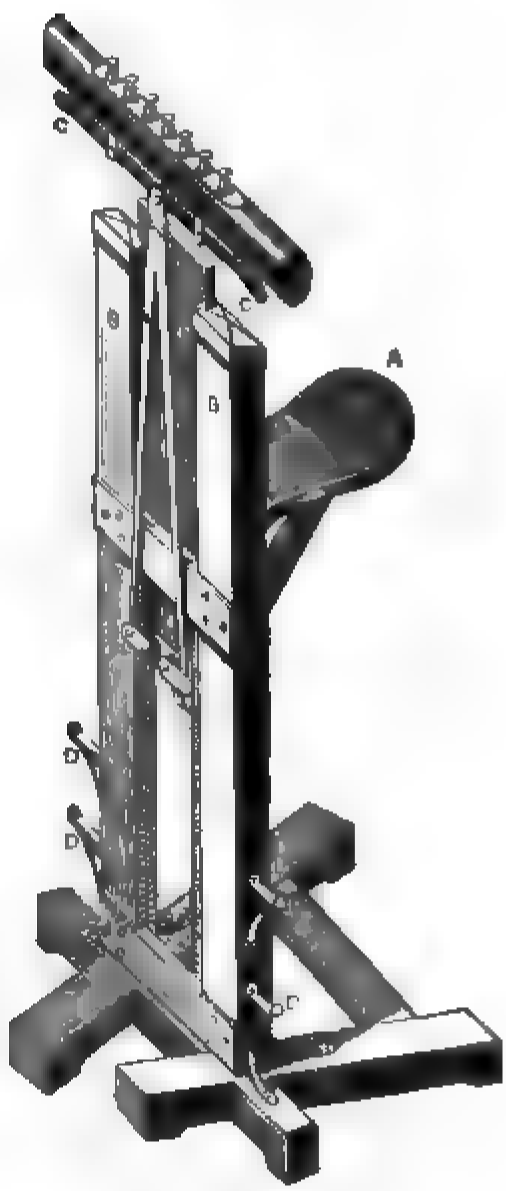
p. See Fig. 1.

q. Iron-toothed *quadrant.*

r. See Fig. 1.

A useful observing-chair for Reflecting Telescopes has been invented by Mr. E. B. Knobel[f]: it consists of a saddle-shaped seat, A, attached to a frame sliding freely in grooves, in two stout uprights B B. On the inside of each of the uprights B B, and attached to them, are strong ratchets, shewn in the engraving; the seat, which moves independently in the grooves between the uprights, is kept in position between them by two pauls which are attached to the lower part of it: these pauls are connected by levers to the handles C C, and can be released by lifting the handles upwards: in this way the position of the seat can be regulated at pleasure. The observer sits astride on the saddle-shaped seat A; if then he rests his feet on one of the pairs of foot-rests D D and clasps the top rail, taking one end in each hand; and in doing so, raises the handles C C until they are in contact with the upper bar, he will release the pauls to which these handles are connected by levers. Now the cross-bar above the handles C C, the sliding-piece between the two uprights, and the seat itself being all connected together, and the weight of the observer being taken off the seat and supported entirely on the foot-rests D D, he can raise or lower it at pleasure as may be convenient. On leaving go of the ends of the top rail, the handles will fall, and the levers falling with them, the pauls will drop into the ratchets, and secure the seat in the position determined on by the observer. The triangular arrangement of the base renders the seat quite steady, and safe at its greatest elevation. The top of the rail may be used to hold a row of eye-pieces as shewn.

Fig. 262.



OBSERVING CHAIR, DEVISED BY E. B. KNOBEL.

[f] *Ast. Reg.*, vol. x. p. 96. April 1872; *Month. Not.*, vol. xxxiii. p. 57. Nov. 1872.

Reflectors being more susceptible to the influence of changes of temperature than refractors should be used as much exposed to the air as possible. If kept under cover they should be uncovered as long and as completely as possible before observations are commenced. Many observers who possess large reflectors keep them altogether out of doors. In such cases they themselves should

Fig. 263.

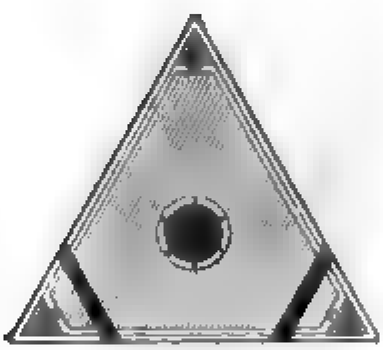
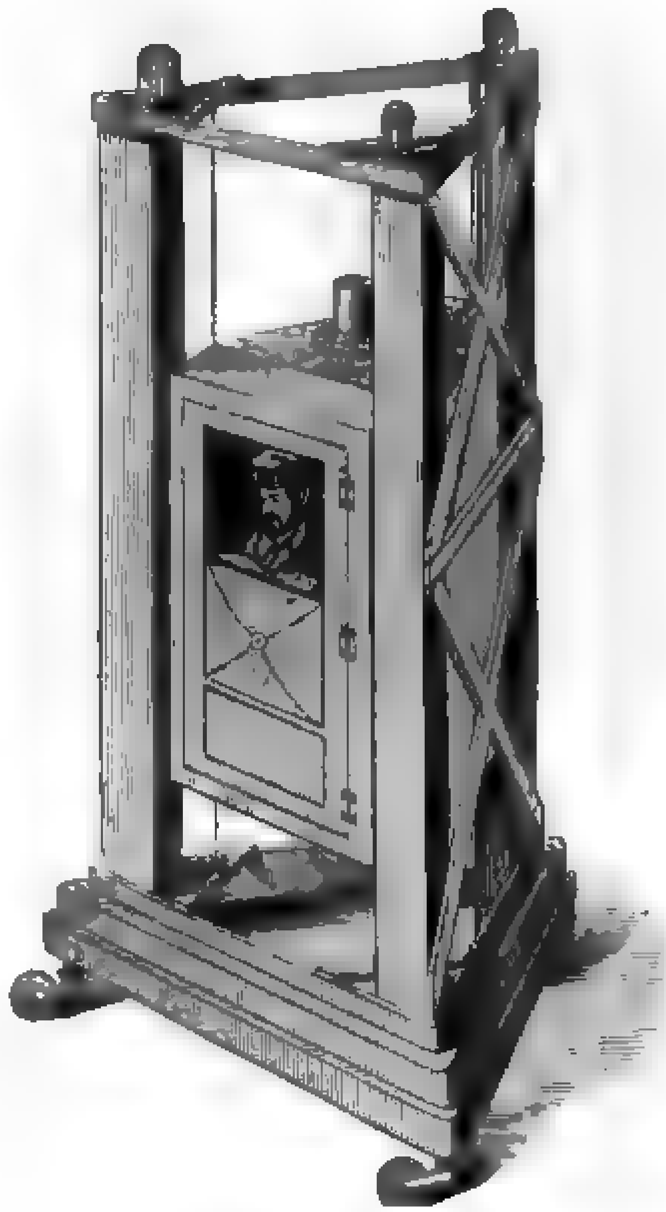


Fig. 264.



Browning's Observing Box.

be under shelter, and for this purpose a sliding "observing box" devised by Browning will be found useful[g]. The construction of this contrivance will be understood from an inspection of Figs. 263–4. In the latter it will be noticed that at each corner of the structure there is a hollow triangular pillar. These pillars are attached to

[g] *Month. Not.*, vol. xxxi. p. 172. March 1871.

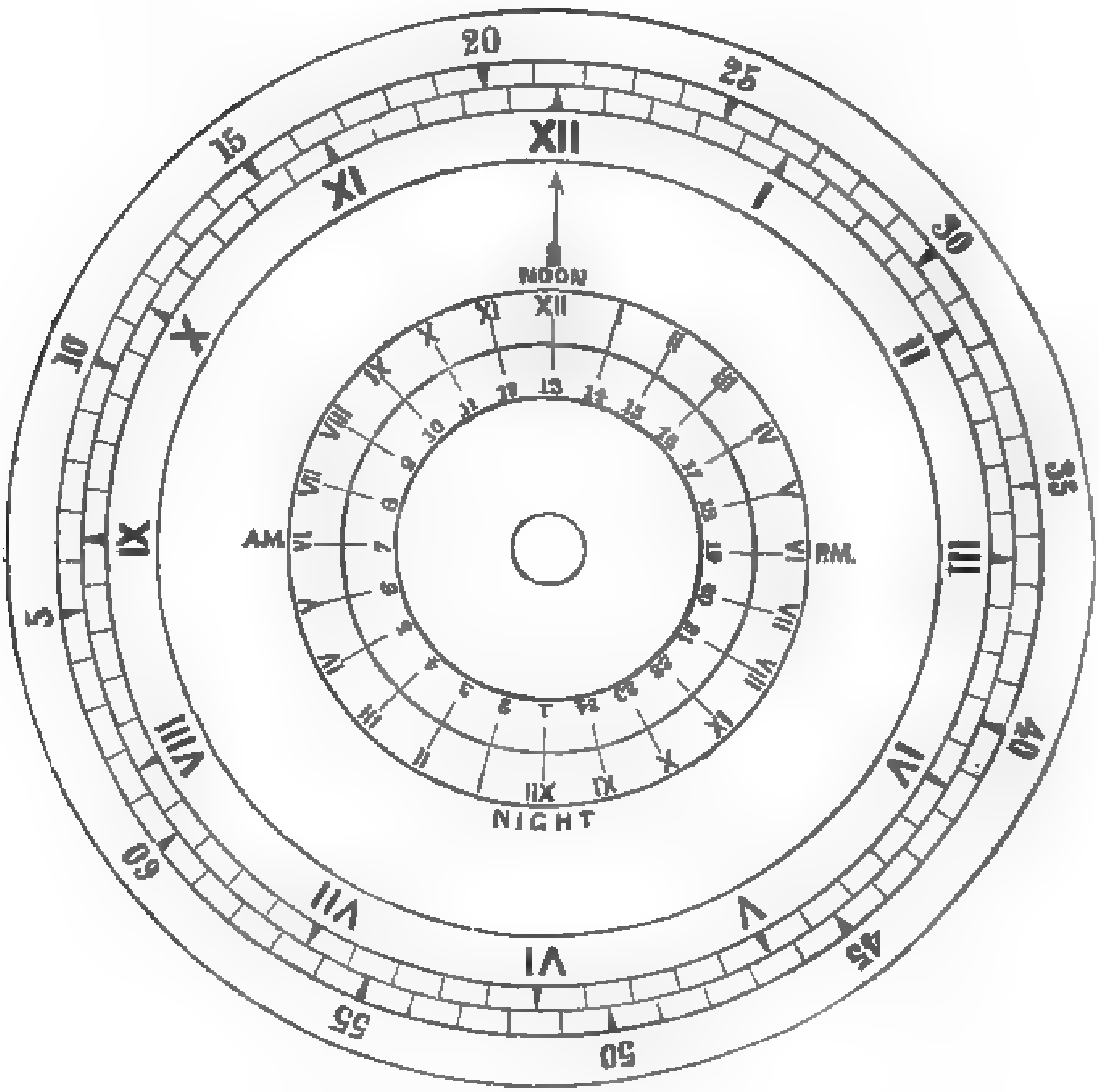
two strong triangles framed of suitable timber. The observing box, which is also triangular in plan, fits loosely between the 3 upright pillars and runs in grooves, placed on the sides which face inwards. The weight of the box is borne by ropes which run over pulleys and down the inside of the hollow pillars. At the end of each rope is a counterpoise, and the three counterpoises must be collectively slightly heavier than the box and the observer therein. A door on one side of the box gives access to it. On the lower edge of the openings in this door and at a convenient height there should be a shelf or desk-slope which may be made a fixture or moveable as may be deemed preferable. The observer sits in an ordinary chair, a chair having been found in practice more comfortable and convenient than any seat fixed to the box. Two strong cords attached to bars running across the front corners of the frame are carried through small circular holes in the top and bottom of the box one on each side of the observer. In order to shift his position the observer has only to take hold of these cords, and if the weight of the box with him in it is counterbalanced with fair accuracy, a very slight amount of muscular force will enable him to move up and down in the frame. A few loose weights should be at hand to vary the adjustment should persons of different weights from the person for whom the box was constructed require to use it. In the roof of the box some provision should be made for ventilation.

In addition to all the above paraphernalia a chronometer, or well-made clock, set to sidereal time is needed. It is by no means necessary in a general way that this should be an expensive or highly-exact instrument; an ordinary good parlour time-piece, costing from £6 to £10, will meet all the requirements of the amateur. In the absence of a Transit Instrument specially intended for the determination of the time, the equatorial (presuming it to be in proper adjustment) set in the meridian—that is to say, with its declination axis horizontal—will give the time with a fair approximation to the truth.

Failing a sidereal clock or some other ready means of obtaining sidereal time, a rude dial constructed as follows will be useful. Carefully cut 3 discs of card-board, respectively 12, 10 and 8 inches in diameter, and fasten them together concentrically in regular order, the smallest uppermost. Graduate the inner edge of the annulus

made by the middle-sized disc on the largest into 60 equal parts to represent minutes of time, marking off every 5th minute with Arabic figures on the outer edge. Graduate the outer edge of the middle disc likewise into 60 equal parts. Immediately within

Fig. 265.



Sidereal Time Indicator.

this graduated annulus graduate another annulus into 12 hours with Roman numerals. Graduate a 3rd annulus at the inner edge of the self-same disc into 24 hours, reckoned by twelves and indicated by Roman numerals corresponding one xii to the xii of the first set of Roman numerals and the other xii to the vi of the first set. Opposite the former xii write the word noon; opposite the latter

xii, the word midnight; opposite the vi on the right-hand side, the letters P.M.; opposite the vi on the left hand, the letters A.M. Graduate the outer edge of the smallest disc into 24 equal parts marked by Arabic figures (which will stand for sidereal hours).

This contrivance should be mounted on a board and hung up so that the noon xii of the middle or mean time disc should always be at the top: it will then be looked at as one looks at a common clock.

To use the indicator nothing more is required than a copy of the *Nautical Almanac* and a respectable watch indicating Greenwich mean time.

To set the dial for any place under the meridian of Greenwich look in the *Nautical Almanac* for the sidereal time at mean noon on the day of the dial being wanted: turn the innermost disc so that the sidereal *hour* given shall be opposite the noon line; then turn the outermost disc so that the sidereal minute or fraction thereof shall also be opposite the noon line.

For places which are East or West of Greenwich the sidereal indicator must be set to a point so many minutes and seconds to the left or right of the noon line as correspond with the longitude (in time) of the place. This adjustment once ascertained, should be preserved by a suitable mark on the mean time minute-circle (on the middle disc). For every 6 hours of mean time that have elapsed since noon, the sidereal minute-circle must (after the time has in the first instance been found) be pushed backwards one division (or minute), or $\frac{1}{6}$ minute for every hour.

Note that when the number 60 of the outermost or sidereal minute-disc intervenes between the noon line and the given mean time minute on the middle disc, as one reads the clock, the reading of the sidereal hour obtained from the innermost disc must be increased by 1^h.

By means of a dial of this sort tolerably well graduated, sidereal time may be ascertained within a few seconds. To facilitate the readings one or several of (or better still, all) the divisions on the mean time minute-circle (on the middle disc) might be divided into 6 equal parts each of which would represent 10 seconds[h].

If your stand is a portable one, and your observations are

[h] The foregoing description has been re-arranged and re-written from a paper in the *Engl. Mech.*, vol. xvi. p. 116. Oct. 18, 1872. The accompanying woodcut I owe to the kindness of the Editor of that paper.

carried on whenever and wherever may be convenient, there are some little precautions to be attended to which may here be dealt with. Avoid a window if possible, especially in winter. The inequality between the temperatures of the external and internal air (which can at best only be reduced to a not very low minimum) will be found productive of currents and disturbances in the air seriously detrimental to satisfactory observation. If you cannot help observing from a window, open it a considerable time before you intend to commence operations. This will tend to mitigate the evil. When your proceedings are terminated, cover up the glass-work, especially the object-glass, before bringing it into a warmer atmosphere; otherwise, in consequence of its being in a chilled state, its transfer into warm air will probably lead to its becoming bedewed, and this can do it no good, and may cause much trouble.

BOOKS, ETC.

These will be ranged in 2 classes: "essential" and "very desirable." Under the former head I include:—

1. An Ephemeris.
2. A Manual of Celestial Objects.
3. A set of Maps.
4. A Manuscript Note-book.

1. Each nation of importance has its own Ephemeris: each says its own is the best. Three may be said to occupy the front rank: the English *Nautical Almanac*, the French *Connaissances des Temps*, and the German *Berliner Astronomisches Jahrbuch*. The amateur will find much useful information in Whitaker's *Almanac* and in the *Astronomical Register* (Office, Clarence Road, Clapton, London), the latter being a periodical which every English-speaking astronomer ought to take in.

2. As Manuals pointing out objects worth looking at, Admiral W. H. Smyth's *Bedford Catalogue* as a large work, and the Rev. T. W. Webb's *Celestial Objects* as a less pretentious one, are unrivalled, and the lists in Book VI. of the present volume will also be found useful.

3. The Maps of the [London] Society for the Diffusion of Useful Knowledge are very clear and complete, but they are of awkward size and much distorted at the edges. Almost as good, but equally

awkward, is Argelander's *Atlas des Nordlichen Himmels*. Heis's *Neuer Himmels Atlas* is a useful work. For general use I have found no maps so handy and at the same time so good as Hind's, published in Keith Johnson's *Atlas of Astronomy*. They give the stars in white upon a blue ground, and this makes them very legible at night.

The 4th book I very strongly recommend. Captain Cuttle's principle of "When found, make a note of it," is pre-eminently sound from an astronomical point of view. Every little circumstance seeming to be out of the common should be placed on record; no harm can be done; the task, if such it be, will not cost much time or trouble, and great results may at some time or other accrue. Many important discoveries have been brought about by observers careful, and habituated, to take note of trivial matters—as witness the discoveries of Uranus and Neptune. Above all things write down your impressions at the moment; otherwise, come the next morning, and their value will be lessened; or it may even happen, and that not seldom, that they will be so confused and muddled as to be of absolutely no value at all. Especially does this apply to drawings. If making notes and taking sketches has no other use, it serves to train the mind to habits of attention and thought, and that is a thing not to be lightly esteemed.

Amongst very desirable books I include—

1. A book of Logarithms.
2. A standard Star Catalogue.
3. One or more General Treatises on the science.
4. A Manual of Practical Astronomy.

1. Of Logarithms, one of the best books is Vega's by Bremiker, of which an English edition is published by Williams and Norgate. Bruhns's *Logarithms*, published with an English Preface by Tauchnitz of Leipzig, 1870, is also a first-class work. Less pretentious is De Morgan's, published by the S. D. U. K., and that published in the "Edinburgh Course" of W. & R. Chambers.

2. The most useful Star Catalogue is that published in 1845 by the British Association: not inferior to it, except that it is less comprehensive (being mainly a circumpolar catalogue), is the Radcliffe. There are many others which may serve one's purpose.

3. Herschel's *Outlines*, Arago's *Popular Astronomy*, Lardner's *Handbook*, and many others, might be suggested under this head. Those who can read German will find several good treatises in that

language, *e.g.* Klein's. Many treatises in French have been published of late years, but one and all are too wordy for "Britishers." The best is Delaunay's *Cours elementaire d'Astronomie.*

4. As a Manual of Practical Astronomy none surpasses Loomis's. It is at once good, concise, and complete. More elaborate is Chauvenet's masterly work, but most amateurs will find that too large.

Having said thus much on the preparations to be made in starting an astronomical campaign, I will conclude with a few hints on the observation of the several classes of celestial objects.

THE SUN.

The intense heat and light of the Sun necessitate under ordinary circumstances the defence of the eye by some special expedients. These are very various, but the interposition of coloured glass between the eye-piece and the eye is the most usual device. The only occasions when nothing is needed is when the Sun is very close to the horizon, or when it is viewed through a thick [*e.g.* London] fog: it is worthy of note that a fog-dimmed Sun is often an extremely well-defined one, the peculiar features of the solar surface being brought out with unusual clearness.

As regards coloured glasses some remarks may be made. The warm colours—red, orange, &c.—must be avoided, though some persons recommend them, and on the whole it may be said that the choice is between neutral tint and green; the latter is most frequently met with, but the former is regarded with most favour by experienced observers. Various astronomers have advocated "dodges," in the shape of chemical solutions and other liquids; some pour their solutions into the eye-piece itself; others arrange them on the outside in glass vessels, with parallel sides: it may, however, well be doubted whether these and such-like expedients are worth a tithe of the trouble and mess to which they give rise. The claims of the wedge of dark glass are of a higher order, and the facility with which it can be slid backwards and forwards as the intensity of the solar light varies, constitutes a strong recommendation. Smoked glass and combinations of coloured glasses—red and green, green and cobalt-blue—have also their partisans[1]. It is necessary to caution the observer that with any

[1] Foucault is said to have once constructed what he found to be a very convenient *helioscope*, by covering the outside face of an ordinary telescope with a thin

telescope in which the Sun is to be viewed without the "Diagonal" eye-piece mentioned in the next paragraph, the aperture must be contracted to 2¾ inches or so, or the dark glasses will quickly be cracked.

The observer whose operations are not hampered by pecuniary considerations, and whose telescope exceeds 3 inches in aperture, will, however, avail himself of more elaborate appliances, such as the "Diagonal" or the "Dawes" solar eye-piece[j].

Dawes's contrivance (it is hardly an "eye-piece") is very useful for general celestial purposes—such as the examination of a faint sidereal object without the presence of a more luminous neighbour.

Concerning another very serviceable method of examining the Sun, I cannot do better than quote the following remarks from the pen of the Rev. T. W. Webb. "There is, however, a totally different mode of observation, which, if less striking, and less adapted for minute details than direct vision, is far more easy and convenient—that of projection: in which the image is transmitted through an ordinary eye-piece, adjusted, by trial till perfect distinctness is obtained, to a large opaque screen at a suitable distance behind it. If this screen is white, smooth, and carefully arranged at right angles to the axis of the telescope, the correct focus being also carefully determined by repeated trial, this method will give a very fair representation of the principal solar phenomena. Mr. Howlett, indeed, who makes great and successful use of it, tells us that he even gets a more perfect view in this way than by direct vision. At the same time it has the great merit of supplying us with an accurate and inexpensive micrometer, the image of the Sun being made by proper adjustment to coincide with a circle graduated by lines into suitable divisions; and thus the position of the spots may be measured, and their progress made evident from day to day. Carrington, one of our best solar observers, employed this mode, projecting the image on plate-glass coated with 'distemper' of a pale straw colour. A large piece of card-board, with a hole in the middle to slip over the object-end of the telescope in the place of the brass cap, must be provided to throw a shade upon the screen; and the latter,

film of silver or gold. Burnished, the metallic surface reflected most of the incident rays, yet transmitted sufficient for forming an image distinct and available for the ordinary purposes of the astronomer.

[j] See *ante*, p. 623.

if measurement is the object, must be attached to a bar made fast to the telescope, and partaking of its motion.

"Hornstein and Howlett, by inserting in the focus of the eye-piece (which for this purpose should be of the 'positive,' or Ramsden construction) a slip of glass micrometrically divided, projects its image, together with that of the Sun, as a scale upon the screen. The latter gives the following dimensions, which may be useful as a guide:—Telescope 3¾ inches aperture; in a darkened room; power 80; card-board screen on easel, 4 feet 2 inches from eye-piece; glass micrometer in focus divided to 200ths of an inch, each division giving about ½ inch on screen, where a corresponding scale is drawn with ink, every 16th of an inch representing about 4″. With other powers other distances would be required for the screen. With a good telescope, magnifying may of course be pushed much further; but beyond 80, or at the most 90, the field would probably fail to admit the whole disc of the Sun[k]. Captain Noble states that he obtains extremely beautiful views of the solar phenomena by fitting on to the eye-piece the small end of a card-board cone, 1 foot long and 6 inches across the larger end, which is fitted by a disc of plaster of Paris, carefully smoothed while wet on a sheet of plate-glass; on this the image is projected, the interior of the cone being blackened, and an opening made in its side to view the face of the plaster screen."

An attentive observer blessed with good eyes and a good telescope, will frequently be able to detect colour on some of the planets, especially on Mars, Jupiter, and Saturn. But for this sort of work large apertures and high powers are indispensable. Browning states that colour on Mars and Saturn is best seen on nights somewhat misty, and with powers based on the ratio of 60 to every inch of aperture. Occasionally, however, much colour may be seen on a perfectly clear night; and a misty night may fail to cause an exhibition of colour—irregularities not readily susceptible of explanation.

THE MOON.

Concerning the Moon I merely pause to remark that a neutral-tint glass of feeble intensity will be found a very useful adjunct

[k] Observers desirous of the fullest information respecting Howlett's arrangements for viewing and measuring spots on the Sun, must consult his paper on "Sun Viewing and Drawing" in the *Intellectual Observer*, vol. xi. p. 429. July 1867.

for the scrutiny of the lunar surface, especially when a telescope of considerable size is employed.

PLANETS.

For the purposes of amateurs possessed of ordinary telescopes, the planets may be ranged under 2 very distinctly-defined classes, the *interesting* and the *uninteresting:* under the former head I include Venus, Mars, Jupiter, and Saturn; under the latter, Mercury, the Minor Planets, Uranus, and Neptune, all of which are practically inaccessible to the telescopes which are usually in the hands of those to whom these pages are primarily addressed.

For viewing the first group of planets no very precise instructions are necessary. Provided that the air is sufficiently favourable for obtaining good definition, almost any power may be used; the higher the better; bearing in mind the fact that the excessive brilliancy of *Venus* makes the day-time the best time for observing it. When close to its inferior conjunction, either before or after, with the illuminated portion of its disc reduced to the thinnest conceivable crescent, hardly distinguishable from a mere curved line, Venus is an object of peculiar elegance. There appear to be grounds for the opinion that Venus is, on the whole, to be seen more satisfactorily with Reflecting than with Refracting Telescopes[1].

The number of features, all of interest, presented by *Saturn* renders this planet a standard one for popular observation.

As a rule the gauze ring must not be expected to be seen with any aperture below 4 inches.

As regards the satellites—any good telescope of 2 inches aperture will shew Titan; 3 inches will sometimes shew Iapetus; 4 inches will take in Iapetus well together with Rhea and Dione, but hardly Tethys; 5 inches will shew Tethys well; 6 inches, Enceladus: but Mimas and Hyperion are beyond the reach of all but the largest instruments in existence. Fletcher has seen Mimas with a glass of 9⅓ inches aperture, but this is an exceptional case.

[1] This idea is expanded by Lassell. He writes:—"It is one of the advantages of a Newtonian reflector, when the alloy of the speculum is well compounded, that colours of planets are more faithfully represented than they can be by refracting telescopes, the want of perfect achromatism in the latter generally introducing some modifying tinge." (*Month. Not.*, vol. xxxii. p. 83. Jan. 1872.)

Respecting the movements of Jupiter's satellites some facts summarised by Proctor will be useful for the guidance of amateur observers:—"In the inverting telescope the satellites move from right to left in the nearer parts of their orbits, and therefore transit Jupiter's disc in that direction, and from left to right in the farther parts. Also note, that *before* opposition (1) the shadows travel *in front of* the satellites in transiting the disc; (2) the satellites are eclipsed in Jupiter's *shadow*; (3) they reappear from behind his *disc*. On the other hand, *after* opposition, (1) the shadows travel *behind* the satellites in transiting the disc; (2) the satellites are occulted by the *disc*; (3) they reappear from eclipse in *Jupiter's shadow* . . . The satellites move most nearly in a straight line (apparently) when Jupiter comes to opposition in the beginning of February or August, and they appear to depart most from rectilinear motion when opposition occurs in the beginning of May and November. At these epochs IV may be seen to pass above and below Jupiter's disc at a distance equal to about ⅖ of the disc's radius. The shadows do not travel in the same apparent paths as the satellites themselves across the disc, but (in an inverting telescope) *below* from August to January, and *above* from February to July[m]."

COMETS, CLUSTERS, AND NEBULÆ.

These objects, one and all, require low powers and low powers only. It may be taken as generally true that nothing beyond the 2 lowest of any series of 6 powers should be employed in their examination, for a certain proportion of *light* to *size* is essential to distinctness of vision; by using an eye-piece of shorter focus (i.e. higher power) we can readily augment the size of the object, but we cannot increase the light afforded by the object-glass: hence in augmenting progressively our magnifying power a point is soon reached, at which the advantage of increased size is wholly neutralised by the dimness and indistinctness of the object, and as with few exceptions the brightest of nebulæ are dim and indistinct compared with the larger planets, it will readily be understood why moderate powers are essential in the one case though not in the other.

[m] *Half-hours with the Telescope*, pp. 86–8.

STARS, INCLUDING DOUBLE STARS.

Stars at low altitudes require a shorter focus than do stars at high altitudes, in order that there may be in both cases equal distinctness of vision[n].

The only restrictions under which the observer of double stars will find himself depend upon the state of the air and the aperture of his telescope; subject to these, he may employ the highest powers he possesses. Using a telescope of 3 inches aperture I have found 120 to be a very serviceable power for doubles whose components varied in distance between 3″ and 12″. For stars less than 3″ apart, 240 was used when the atmosphere permitted, whilst stars wider than 12″ looked prettier under powers lower than 120. The utmost I ever achieved with the above instrument (an excellent one, by Cooke) was to see the 3 stars of the Triple 12 Lyncis, the 2 nearest of which are only 1·6″ apart.

In scrutinising difficult doubles, Sir W. Herschel's advice may be followed with advantage: he recommended that the focus should be previously adjusted upon a single star of nearly the same altitude, size, and colour, alleging that when this was done the peculiar aspect of the double star would afterwards more strikingly appear.

With an E. wind the telescopic discs of stars often become most provokingly triangular. This may be stated most positively to be a matter entirely independent of the optical quality of the object-glass used. Dawes provided an effectual remedy by cutting off 3 equi-distant segments from the whole aperture of the object-glass. The base of each segment must be the chord of 60°. The chords being placed so as to coincide in position with the angles of the telescopic inverted image, those angles will be as it were clipped off and a fairly round image will be obtained. The form of the faulty image is usually somewhat that of an obtuse-angled spherical triangle[o].

Faint stars, and indeed faint celestial objects of any kind, will often be seen by viewing them from the side of the eye when direct vision fails to make them apparent. The cause of this is not

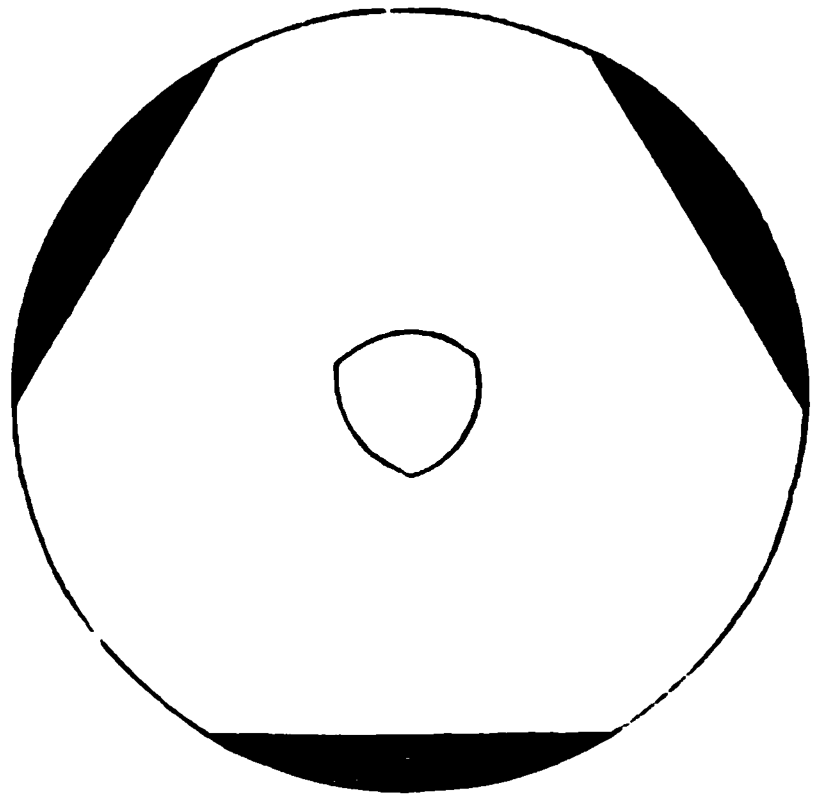
[n] With this note, which I believe is due to Dawes, accords an observation of Noble's to the effect that on one occasion during a haze he found the focus of his telescope become shorter by $\frac{1}{10}$ inch, a state of things which ceased when the haze disappeared, the focus resuming its ordinary place. (But see *Month. Not.*, vol. xxvii. p. 282. June 1867.)

[o] *Month. Not.*, vol. xxvii. p. 232. April 1867.

clear, but the fact that this device is frequently successful when all others fail, admits of no doubt. When about to examine faint objects the eye should be prepared by undergoing a little preliminary training, such as is afforded by 5 or 10 minutes rest in the dark: its discerning power will then be much strengthened.

The apparent inequality of the two components of a double diminishes as the light of the telescope is increased. Some observers find it convenient to set apart for the scrutiny, especially, of coloured doubles, of an eye-piece which has a narrow strip of tin-foil stretched across its field, and so permits the observer to block out one component: a better judgment can then be formed as to the other.

Fig. 266.



PLAN FOR CURING TRIANGULAR STAR-DISCS.

As to the separating power of telescopes of various apertures Dawes has given the following figures derived from an empirical formula of his own.

Aperture.	Least separable distance.	Aperture.	Least separable distance.
Inches.	"	Inches.	"
1·0	4·56	6·0	0·76
1·6	2·85	6·5	0·70
2·0	2·28	7·0	0·65
2·5	1·82	7·5	0·61
3·0	1·52	8·0	0·57
3·5	1·30	10·0	0·45
4·0	1·14	12·0	0·38
4·5	1·01	15·0	0·30
5·0	0·91	30·0	0·15
5·5	0·83		

He remarks:—"It might be not unreasonably imagined that the brightness of the stars would make a great difference in the central distance to which any given aperture could reach. But though it may make *some* difference, it is in fact far less than would at first sight appear probable. This arises from the much higher powers which the brighter star will bear; and as the diameter of the discs does not increase in proportion to the power, the separability of a magnitude is nearly the same, provided the state of the air is such as to bear well the increase of power[p]." The formula on which the above table is based is—

$$\text{Separating power in seconds of arc} = \frac{4{\cdot}56}{\text{aperture in inches.}}$$

It often happens that a smaller aperture will show a very delicate and close comparison to a bright star when a larger aperture fails to show it.

Some nights are more favourable than others for the discrimination of minute differences of colour in stars. Differences of atmospheric condition are no doubt the cause of this, and indeed, if we were better acquainted than we are with the influences of the atmosphere on astronomical optics, it is probable that many discordances and contradictions that have been noted by observers would be found capable of being reconciled.

With respect to the observation of stars for the purpose of taking notes of colour Webb makes some remarks and suggestions which deserve a place here:—"It may often be found of service to put the object considerably out of focus either way, as the hue of a disc may be more sensible than that of a point; and we may thus in some cases escape errors due to the imperfect achromaticity of the object-glass, which will not be equally apparent on each side of the focus of which I have had experimental certainty. It is safest to estimate the tint in the centre of the field as the Ramsden ocular [*i. e.* eye-piece] is never achromatic, and other eye-pieces claiming that quality do not always possess it. A state of atmosphere in which the sun would have a ruddy cast ought of course to be avoided, and colours cannot be depended upon in our climate and under ordinary circumstances within some distance of the horizon, as they are interfered with by the refractive action of the atmosphere. 'In addition,' Smyth tells

[p] *Mem.* R.A.S., vol. xxxv. p. 159. 1867.

us, 'to the colouring and absorbing effect of the atmosphere increasing so excessively low down on the horizon, the envelope acts so strongly there as a prism, that combined with the bad definition prevailing, I have sometimes seen a large star of a really white colour appear like a blue and red handkerchief fluttering in the wind; the blue and red about as intense and decided as they could well be.' W. Struve found these prismatic colours visible in a dark field as far as 30° and their traces even to 45° from the horizon, and every estimate below 15° was worthless. The same authority has stated that the tints are not to be trusted on the blue background of a day-light sky. In fact, every deception arising from contrast ought to be guarded against, and this source of error operates in more than one way. A retina which has recently been exposed to artificial light, hardly ever of a pure white, will require to be kept in the dark for a little time in order to pass an unbiassed judgment; and the presence of a large and strongly-coloured star in the field will be sure to tinge its feebler neighbours with the complementary hue: and this may no doubt be to a certain extent the reason why so many minute companions to orange or yellow stars have been entered as blue, but it is certainly not the sole cause[q]."

The amateur astronomer who commences anything like systematic observations of the fixed stars, will find himself confronted by a difficulty which really involves points of such moment that it is surprising that so few attempts have ever been made to grapple with it. I am alluding to the estimation of star magnitudes, sometimes, rather pompously, talked about as "Stellar Photometry." The vagueness of language in use respecting star magnitudes is as surprising as it is unsatisfactory, and when one considers the precision which characterises modern science, one is astonished that so little has been done to remove it. I do not think it too much to say that *estimates of star magnitudes not based on methodical experiment are rarely trustworthy;* and this often applies even to statements made by experienced observers.

To Dawes is mainly due the credit of initiating a genuine reform as to this matter. *The principle* of his suggestion is to diminish the light of the stars examined so as to reduce them to some

[q] *Student,* vol. v. p. 487.

common standard of brightness. This is done (1) by diminishing the aperture of the telescope employed till the star under comparison becomes barely but steadily visible; and (2) to take as the standard aperture that which just secures visibility to the average of several of Argelander's stars of the 6th magnitude. "Assuming, then, the obvious principle that if two stars, as viewed through a telescope, appear equally bright, the illuminating powers employed (that is, the areas of the portions of the object-glass employed) must be inversely proportional to their magnitude or real brightness, it is easy to calculate the areas of the portions that must be left exposed to render *just* visible the stars arranged according to a definite scale of magnitudes," and to provide by means of the formula given a series of pasteboard rings that can be readily numbered and applied to any particular telescope. To put this idea into practice the first thing that an observer must do is to determine experimentally for himself what is the aperture of the telescope he uses which will give the desired visibility to average stars of the 6th magnitude, and thence to determine the apertures corresponding to smaller magnitudes. Of course in obtaining the standard of aperture for an average 6th magnitude star (on which the other apertures depend) reliance must not be placed on one star only; at least a dozen should be made use of.

In working out this matter Dawes stated that he had intended to adopt Sir J. Herschel's scale, as generally avoiding the use of half-magnitudes, but that eventually he decided to conform to Struve's ratio of progression in order that his results might be comparable with those obtained by such leading observers as La Lande, Piazzi, Bessel, and Argelander.

Putting m = the standard magnitude; a the aperture necessary to show it; μ = any other inferior magnitude, and x = the aperture necessary to render visible a star of magnitude μ, we shall obtain the equation:—

$$x = a \times 2 \mu - m.$$

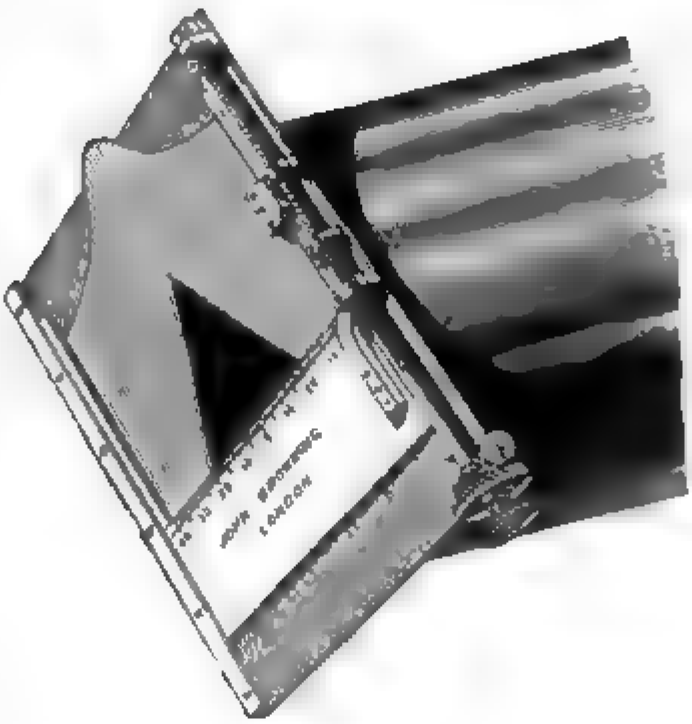
Of course one and the same power must be used invariably in operating with a series of apertures thus obtained.

When the apertures corresponding to each magnitude and half-magnitude have been thus ascertained by calculation, a series of discs must be prepared and pierced as may be requisite. Many

persons will be able to do what is necessary themselves, but if not, the assistance of an instrument maker must be sought[r].

A useful astrometer, for determining star-magnitudes by the method of limiting-apertures, has been invented by Mr. E. B. Knobel[s]. It consists of an equilateral triangular aperture which, though retaining the triangular form and always concentric, can be gradually reduced in size from the inscribed triangle to zero. To accomplish this the triangle is constructed of two plates, one of which forms the base, and the other contains the opposite angle. These plates are connected by a screw-shaft, the upper portion of

Fig. 267.



Knobel's Astrometer.

which, carrying the angle-plate, is a *right-handed* screw, and the lower portion carrying the base-plate is a *left-handed* screw: moreover the pitch of the upper screw is exactly *twice* that of the lower. By causing the shaft therefore to revolve the plates either approach or recede from each other, the angle-plate moving twice as fast as the base-plate, which by a property of the equilateral triangle, ensures the concentricity of the aperture. A micrometer-head fitted to the shaft gives accurately the length of the side of the triangle, whence

[r] See *Month. Not.*, vol. xi. p. 187. June 1851; vol. xii. p. 80. Feb. 1852; vol. xiii. p. 277. 1853.

[s] *Month. Not.*, vol. xxxv. p. 100. Dec. 1874.

the area is easily obtained. Mr. Browning turns out instruments of this make which are very perfect, and fulfil all the requirements of practical observers.

Dawes, by making a trifling addition to his solar eye-piece, succeeded in converting that into a useful instrument for determining the brightness of stars of unknown magnitude. He had fitted to it sliding wedges of neutral-tint glass of different depths of shade. A wedge is first used on some star assumed to be of a definite recognised magnitude and therefore available as a standard. The wedge is moved across the eye-piece and adjusted so that the star is just visible and no more. The position of the wedge relative to some zero point on the eye-piece is then marked. Supposing now that the star observed was of the 8th magnitude; any other unknown star which is similarly visible with the wedge in the same position would also be of the 8th magnitude, and so on with other magnitudes as experiment might shew, marks applicable to the different magnitudes being made on the wedges.

This wedge arrangement combined with a "Dawes' Solar Eyepiece" offers great facilities for the determination of the magnitudes of the components of double stars—a matter otherwise of no small difficulty. By having resort to the smaller holes in the diaphragm as may be found convenient, it is possible to isolate one star of a pair from its companion and gauge its light with certainty. This done the resulting values will be sometimes very different from, and always much more trustworthy than, ordinary eye-estimations. For instance, Dawes stated that there resulted a difference of more than a whole magnitude of Struve's scale in his estimation of the brightness of the small companion to α Lyræ according as the principal star was or was not visible at the time when an observation was made [t].

Whilst on the subject of star magnitudes it may be well to present the reader with a useful Table of comparative magnitudes, given by Webb [u] at the instance of Knott. It represents in terms of Smyth's magnitudes the equivalent magnitudes of Sir J. Herschel, W. Struve, and Argelander. The fact that Smyth's values are based upon Piazzi's is deemed by Webb, and I think justly, an additional reason for putting them to the front, but it is impossible to deny that Struve's values (based on the scale of 1–12 for stars

[t] *Month. Not.*, vol. xxv. p. 230. June 1865. [u] *Celest. Objects*, p. 173.

visible in the great Dorpat refractor) have met with much acceptance both in England and on the continent. The Table is restricted to telescopic magnitudes, there being a fair agreement as regards stars visible to the naked eye.

Smyth.		J. Herschel.		W. Struve.		Argelander.
6	=	6·4	=	5·7	=	5·9
6·5	=	7·0	=	6·3	=	6·4
7	=	7·4	=	6·5	=	6·8
7·5	=	7·8	=	6·9	=	7·5
8	=	8·2	=	7·4	=	8·0
8·5	=	8·8	=	7·9	=	8·6
9	=	9·5	=	8·3	=	9·0
9·5	=	10·1	=	8·9	=	9·4
10	=	10·4	=	9·3	=	9·4
11	=	11·3	=	10·0	=	10·0
12	=	11·7	=	10·4	=	10·6
13	=	12·5	=	10·7	=	11·2
14	=	13·3	=	10·9	=	11·8
15	=	14·5	=	10·9	=	12·4
16	=	15·9	=	10·9	=	13·0

MISCELLANEOUS REMARKS.

Be content in general to use low powers. Much time and patience are often wasted in hopeless endeavours to bring out with high powers details which will not come out because the atmosphere is unfavourable, or the object-glass inferior, or the observer's eye out of condition. High powers are also objectionable because they diminish the field of view and the illumination of the object under examination, magnify the speed with which the diurnal motion causes an object to pass out of the field, and exaggerate all imperfections of lenses, and stands, and of the atmosphere.

The best kind of light for use in an observatory (or out of it) is that which is afforded by a bull's-eye lantern, as by means of it you can throw the light on your books or maps without materially distracting the eye. Gas has much to recommend it on the score of cleanliness and saving of time and trouble, but the excessive heat which it gives out produces so many currents of air that even with the utmost precautions as to ventilation annoyance will be experienced by the spoiling of the definition. A red shade, consisting either of tinted glass or of red silk tied over the bull's-eye of the lantern, is useful when the observer is passing from the examination of a map or book to that of a delicate object; as the eye is less tried by the red than by the white light.

The light for illuminating the wires of the transit instrument should enter through a piece of red glass, which least of all colours affects the eye, and the observations will be much more trustworthy if made with the minimum amount of light which will permit the wires and the star to be clearly seen.

The most convenient kind of coat for an observer is a common shooting coat, as its front pockets are very useful as receptacles for eye-pieces and so forth; and as regards head-gear, nothing is better than a simple skull-cap without peak or brim of any kind. I have long used a Turkish fez, but it is rather hot in summer weather.

Nights on which stars shine brightest to the naked eye are frequently of little value for astronomical observation, whilst hazy dull-looking nights often enable important features to be brought out; this is specially the case with the larger planets [1].

As regards the number of nights in the year available for telescopic work perhaps it would not be very profitable to attempt to say much. Mr. W. Lawton, from observations at Hull extending over 22 years, finds the number of nights cloudless, or nearly so, up to midnight, to range, omitting fractions, from 7 for January, February, July, and December, to 9 for May, June, September, and October, the most cloudless month being April with 10 nights. March, August, and November each yielded 8 nights apiece. This reckoning takes no account of quality, only of freedom from cloud.

Sir J. Herschel recommended the use of a round disc of thin metal or card-board, placed centrally in front of the object-glass, and having a diameter of from $\frac{1}{6}$ to $\frac{1}{5}$ that of the object-glass. This increases the *separating* power of a telescope, but as it also augments both the number and the sizes of the rings round bright stars, its value on the whole is somewhat dubious.

Dawes adopted and recommended the practice of covering the entire object-glass with perforated card-board, such as that employed in Berlin wool-work. The effect of this expedient in producing sharpness of definition he considered to be very marked. When the object to be viewed was not bright enough to bear the loss of light thus arising, he found that something like the same

[1] A striking instance of the truth of this is furnished by the history of the discovery of Saturn's dusky ring. The night on which G. P. Bond found it was so hazy that none but bright stars were visible to the naked eye.

good results might be obtained with a piece of card-board of the size of the object-glass pierced with holes of equal size (about $\frac{1}{8}$ of an inch in diameter) arranged in concentric circles.

In operating with a telescope which is not very steady on its stand, it is a good plan to direct the instrument not on to the object you want to see but towards a point one or two fields *preceding* it, and await the passage of the object (by the diurnal motion) across the field. Proceeding thus, the tremors of the telescope have a little time to settle down, and the scrutiny may eventually be performed under more favourable circumstances than would otherwise be possible.

Those who specially desire to devote themselves to the delineation of celestial objects, will do well to study a useful paper on Astronomical Drawing written many years ago by Prof. C. P. Smyth [y].

Methodical astronomical observation will be greatly facilitated by the employment of printed forms on which to record the results arrived at. I append 3 such forms, which I have found very useful in their several departments.

1. FORM FOR STAR TRANSITS.

No.______ Date______________

Star______________ Decl.______________

							m. s.
Wire I.	..	..	..	..	..	..	
II.	..	..	..	..	..	..	
III.	..	..	..	..	..	..	
IV.	..	..	..	..	..	..	
V.	..	..	..	..	..	..	
							·2
						Mean wire	
							h.
Observed passage	..	..	..	..	..		
R.A. of star	..	..	..	..	..		
Clock error..	..	..	..	..	..		

[y] *Mem.* R.A.S., vol. xv. p. 71. 1846.

2. FORM FOR OBJECTS TO BE OBSERVED.

No.______ Date________________

Object.	R.A. h. m. s.	Decl.	Memoranda.	Remarks.

3. FORM FOR CIRCLE READINGS.

No.______ Name______________________ Date____________

	R.A. h. m. s.		Declination
	24 0 0	Vernier A.	
Vernier A.		B.	
B.		Mean reading ..	
		[Therefore decl. =	]
		Refraction	
Mean reading ..		True decl.	
Therefore hour angle =			
Clock			
Deduced R.A. ..			
Clock error			
True R.A.			

No. 1 requires no explanation. [See *ante*, p. 676.]

No. 2 will be found to conduce greatly to the economy of time on a good night. All the observer has to do is to write out in the day-time the objects which he wishes to examine, with their positions (revised for precession if needful[a]) accompanied by a *précis* of their striking features; then when evening arrives he is ready for action without the mortification of losing half of a valuable night in deciding what to look for, and in rummaging over a dozen books to acquaint himself with the whereabouts of what he desires to look for. The observer's own notes are to be set down in the last column, and may be transcribed at leisure.

No. 3 will be found of less frequent applicability. It is useful when an observer has picked up a strange object whose position he wishes to ascertain approximately, merely for purposes of identification. If the declination circle of the observer's instrument reads polar distance, an extra line (bracketed in the form given above) must be inserted for the subtraction of the mean reading of the circle from 90° to arrive at the declination.

A committee of the British Association appointed to collect and digest observations of luminous meteors has published a paper of directions and suggestions, of which the following is an abstract:—

1. Compare with magnitudes of stars, brightness of planets, or diameter of Moon.

2. State whether brightness increased or decreased during the appearance, noting colours, if any, in the head, train, or sparks.

3. Distinguish the kind of streak or train, whether continuous, broken, or afterwards becoming curved; if stationary for many seconds, examine it with a telescope, if possible.

4. State estimated duration of flight; and, as far as possible, precise time of disappearance, especially if larger than Venus at her brightest.

5. Give the apparent course, as from one star to another; or the altitudes and either the true or the compass bearings (stating which) of the points of appearance and disappearance. In general prolong the apparent course to the horizon, and note from what point of the compass to another it moved *as estimated at the horizon;* record also the apparent length of path.

6. Note any unusual peculiarity of path, as curved or serpentine; or of form, as elongated or double; or whether it bursts.

7. In case of the bursting of very large meteors, listen attentively for any noise for some minutes, noting the intervening time.

8. In such cases, make special inquiry in the neighbourhood as to whether anything has been seen to fall.

[a] But this will rarely be needful, unless very old catalogues and lists of objects have to be relied on.

9. If many are seen on any one night, state number of observers and condition of the sky, amount of moonlight, and hourly number of meteors, or hourly number of meteors of different mags. (1st to 5th mag. stars), average duration and length of path, general appearance, streak (if any); and note the radiant point.

10. It is desirable to make especial observations on every fine evening, from 9 to 10 P.M. in winter, and from 10 to 11 P.M. in summer; and if on any night meteors should be found to be more than usually numerous between these hours, to extend the watch on that night somewhat longer.

11. The days in each month most favourable for seeing meteors may be stated to be as follows:—Jan. 2 and 15–19; Feb. 10 and 19; March 1–4 and 16; April 20 and 26–May 3 (a.m.); May 18; June 6 and 20; July 17, 20, and 29; Aug. 3, 7–13, especially 10; Sept. 1, 6, 10; Oct. 1–6 and 16–23; Nov. 12–14, 19, 28, and 30; Dec. 6–14, especially 11, and 24; at which times it is very desirable to notice as accurately as possible their proper direction as compared with that of the Earth, in accordance with the instructions noted in No. 5.

Table for recording Observations on Luminous Meteors.

Date.	Hour.	Place of Observation.	Apparent Size.	Colour.	Duration.	Position, or Altitude, and Azimuth.	Appearance; Train or Sparks; Streak, if any left, and its Duration.	Length of Path.	Radiant point; direction; slope of Path.	Remarks.	Observer.

The use of some such a Table as this will greatly facilitate methodical observation and the accurate recording of results.

CHAPTER IX.

HISTORY OF THE TELESCOPE.

Early history lost in obscurity.—Vitello.—Roger Bacon.—Dr. Dee.—Digges.—Borelli's endeavour to find out who was the inventor.—His verdict in favour of Jansen and Lippersheim of Middleburg.—Statements by Boreel.—Galileo's invention.—Scheiner's use of two double-convex Lenses.—Lenses of long focus used towards the close of the 17th century.—Invention of Reflectors.—Labours of Newton.—Of Halley.—Of Bradley and Molyneux.—Of Mudge.—Of Sir W. Herschel.—Of the Earl of Rosse.—Of Mr. Lassell.—Improvements in Refracting Telescopes.—Labours of Hall.—Of Euler.—Of the Dollonds.—The largest Refractors yet made.

THE early origin of the telescope, like that of many other important inventions, is lost in obscurity, and it is now impossible to determine who was the first maker. It is certain that some time prior to the end of the 13th century lenses were in common use for assisting to procure distinctness of vision. A certain Vitello, a native of Poland, seems to have done something in this line; and Roger Bacon, in one of his works, employs expressions which shew that even in his time (he died in 1292) spectacles were known[a].

Seeing that this was the case, it is almost certain that some combination of 2 or more lenses must have been made in the interval which elapsed between Bacon's time and the commencement of the 17th century, when telescopes are usually considered to have been invented. Dr. Dee[b] mentions that though some skill is required to ascertain the strength of an enemy's force, yet that the commander of an army might wonderfully help himself

[a] *Opus Majus*, part iii. cap. iv. p. 357, ed. S. Jebb, fol. London 1773.
[b] Preface to Euclid's *Elements*, 1570.

by the aid of "perspective glasses," a phrase which must refer to some kind of optical instrument then in use. The well-known old philosophical writer, Digges, states that "by concave and convex mirrors of circular [spherical] and parabolic forms, or by paires of them placed at due angles, and using the aid of transparent glasses which may break, or unite, the images produced by the reflection of the mirrors, there may be represented a whole region; also any part of it may be augmented, so that a small object may be discerned as plainly as if it were close to the observer, though it may be as far distant as the eye can descrie [c]."

A second edition of Digges's work, edited by his son, was published in 1591, in which the latter affirms that "by proportional mirrors placed at convenient angles, his father could discover things far off; that he could know a man at a distance of 3 miles, and could read the superscriptions on coins deposited in the open fields." Though these statements may be exaggerations, yet it cannot be open to doubt that some kind of optical instruments were known to the writer in question.

A claim to the invention of the telescope has been put in on behalf of Baptista Porta, who lived between 1545 and 1618; it is probable, however, that all he noticed was, that an object viewed through a convex lens was apparently enlarged in size.

Towards the middle of the 17th century, Borelli, a Dutch mathematician of some repute, published a book [d] containing the result of inquiries carried on by him for ascertaining what he could connected with the invention of the telescope. He decides, on the whole, in favour of Zachariah Jansen and Hans Lippersheim, two spectacle-makers of Middleburg, Holland. In a letter written by Jansen's son, the date of the discovery is stated to have been 1590, though another account makes it 1610. In the same work is given a letter, written by M. Boreel (Dutch minister at the Court of St. James's), who mentions that he was acquainted with the younger Jansen, and had often heard of his father as the reputed inventor of the *microscope*, adding that telescopes were first made in 1610 by Jansen and Lippersheim, who presented one to Prince Maurice of Nassau, by whom they were desired to keep secret their discovery, as he thought he might, by means of one

[c] *Pantometria*, 1571.
[d] *De Vero Telescopii Inventore*, 4to. Hagæ 1665.

of these instruments, obtain advantages over the enemy, Holland being then at war with France.

Boreel further mentions that Adrian Metius and Cornelius Drebbel went to Middleburg and purchased telescopes from Jansen. Descartes's account differs from this. He says[e] that about 30 years previous (to 1637, when his book was published), Metius, who was fond of making burning-glasses, by chance placed at the end of a tube 2 lenses, the one thicker and the other thinner in the middle, than at the edges, and thus formed the first telescope. It is now impossible to reconcile these discrepancies. Harriot observed the Sun with a telescope in the year 1610, as we learn from his papers, edited and published a few years ago by Professor Rigaud, but there is no evidence to shew whether it was of English or foreign construction.

Whatever may have been the exact period at which the telescope was invented, certain it is that the knowledge of it was for some years confined to northern Europe. Galileo knew nothing of it until 1609, when he casually received some information on the subject from a German whom he met at Venice. He mentions that he then desired a friend at Paris to make certain inquiries for him. On receiving some information to guide him, he was enabled to contrive a telescope on the principle already referred to, magnifying no less than 3 times! He subsequently made one which magnified 30 times. The fruits of this discovery are well known, and include spots on the Sun, the satellites of Jupiter, the phases of Venus, &c.

Though a telescope made on this principle is exceedingly defective for viewing distant objects, on account of the small field which it embraces, yet some years elapsed before any improvement was made.

Kepler first pointed out the possibility of forming telescopes of 2 convex lenses[f], but he did not reduce his idea to practice, neither was it done for many years afterwards. Scheiner, in 1650, described an instrument of this kind, adding that he shewed one to the Archduke Maximilian 13 years previously[g], and that the images were inverted. About this time De Rheita constructed telescopes of 3 lenses, which combination he stated gave a better

[e] *Dioptrica*, cap. i.: Lugduni Batavorum 1637.
[f] *Ibid.* [g] *Rosa Ursina*, &c.

image than 2; he also made binocular telescopes, instruments having 2 tubes side by side, and furnished with similar magnifying powers. I have already spoken of chromatic aberration, and of the immense focal length of some of the lenses used for telescopes. This was towards the close of the 17th century. Campani of Bologna, in 1672, made for Louis XIV. a telescope, the focal length of whose object-lens was 136 feet; Auzout had one 600 feet, but it seems that he was unable to use it, and no wonder. Huyghens presented one to the Royal Society which had a focus of 123 feet[h], and which is still preserved by that body. Practical astronomy is indebted to Huyghens for the Negative Eye-piece—a most valuable invention.

The extravagant lengths which the dioptric telescopes had now reached resulted in attempts being made to see whether an equal magnifying power could not be attained in some other manner.

Mersenne, in 1639, suggested the employment of a spherical reflector for forming an image which might be magnified by means of a lens. Descartes, to whom the proposal was submitted, ridiculed it, and in consequence (we may presume) the idea was dropped. However, in 1663, Gregory renewed it, though it does not appear that he had any previous knowledge of what Mersenne had proposed, using, instead of a spherical, a paraboloidal speculum. He came to London for the purpose of getting an instrument of the kind constructed, but not finding any workman who could do it, he was obliged to relinquish the project.

Shortly after, Newton, finding that it was impossible to overcome the aberration caused by the unequal refrangibility of the different coloured rays of light, gave up the hope of constructing refracting telescopes which were likely to be of any great use, and turned his attention to the manufacture of reflectors. Having in 1669 found an alloy which he thought would be suited for a speculum, he cast one and ground it with his own hands, and early in 1672 he completed 2 telescopes, a detailed account of which he transmitted to the Royal Society[i]. The radius of the concavity of the one was 13 inches, and its magnifying power, 38. In the same year that Newton finished his telescopes, Cassegrain proposed the arrangement which now bears his name, though it

[h] *Astroscopia Compendiaria*: Hagæ 1684. [i] *Phil. Trans.*, vol. vii. p. 4004. 1672.

does not appear that he actually constructed a telescope. The first reflecting telescope, the speculum of which was pierced in the centre so as to permit objects to be viewed by looking at them directly, was made by Hooke in 1674[k].

Very little progress was made in the improvement of reflecting telescopes for many years, in consequence of the difficulty of obtaining metal suitable for specula. In 1718 Hadley made 2, each 5 feet long[l]; and Bradley and Molyneux, in 1738, succeeded in making a satisfactory one[m], and having instructed two London opticians, Scarlet and Hearne, they made some for general sale. Short and Mudge were also labourers in this field[n]. They were soon followed, and completely eclipsed, by Dr. (afterwards Sir William) Herschel[o]. In late years the Earl of Rosse[p], Mr. De La Rue, and Mr. Lassell have ground some very large and perfect mirrors. The most recent and at the same time successful labourers in this field are the Rev. H. C. Key and Mr. With.

Though the above improvements were progressively made in reflecting telescopes, it must not be supposed that attempts to obtain achromatic combinations of glass lenses were abandoned. In 1729, Mr. Chester More Hall, of More Hall near Harlow, Essex, being of opinion that an examination of the physical constitution of the eye would afford some clue to the best means for forming achromatic combinations of lenses, set to work, and at length succeeded in obtaining the much-desired result—an image free from colour. Several persons are said, towards the close of the last century, to have possessed telescopes made by, or under the superintendence of, Mr. Hall[q].

In 1747 Euler came to the same determination as Hall, but did not obtain the same successful results. He proposed to employ a lens compounded of glass and water, but it was a signal failure[r].

Dollond in 1758 invented the achromatic combination now in use, for which he received from the Royal Society the Copley Medal; and in 1765 his son, Peter Dollond, found that spherical aberration could be diminished by using 3 lenses of different kinds of glass[s].

[k] Birch, *Hist. Roy. Soc.*, vol. iii. p. 122.

[l] *Phil. Trans.*, vol. xxxii. p. 303. 1723.

[m] Smith's *Opticks*, vol. ii. p. 302.

[n] *Phil. Trans.*, vol. lxvii. p. 296. 1777.

[o] *Ibid.*, vol. lxxxv. p. 347. 1795.

[p] *Phil. Trans.*, vol. cxl. p. 499. 1850.

[q] *Gent. Mag.*, vol. lx. part ii. p. 890. 1790; and see a paper by Wackerbarth in *Month. Not.*, vol. xxviii. p. 202. May 1868.

[r] *Transactions of the Berlin Academy.* 1747.

[s] *Phil. Trans.*, vol. l. p. 733. 1758.

Since this period great advances have been made in the manufacture of telescopes, more especially in respect of the size and purity of the glass employed.

Amongst the observatories possessing refractors of the largest size may be mentioned Washington U.S., Pulkova, Cambridge U.S., Paris, Greenwich, Cincinnati U.S., Cambridge (England), and Munich; all of which have instruments with object-glasses exceeding 11 inches aperture. The largest object-glass in existence is one finished in 1876 by Grubb of Dublin for the Imperial Observatory at Vienna. It has an effective aperture of 26 inches. The aperture of the Washington object-glass is nearly the same. Scarcely inferior to these in *size* is that completed in 1870 by Cooke of York for Mr. R. S. Newall of Gateshead. It has an effective aperture of 25 inches.

BOOK VIII.

A SKETCH OF THE HISTORY OF ASTRONOMY[a].

IT is not my intention to enter into a regular history of Astronomy, for that would occupy more space than could be afforded for the purpose; what I shall here attempt will be simply a chronological summary of the rise and progress of the science from the earliest period[b].

It is difficult to assign any exact date for the origin of Astronomy, so ancient and so lost in obscurity is it: I begin therefore with—

B.C.

720. Occurrence of an eclipse of the Moon, observed at Babylon, and recorded by *Ptolemy*.

719. Occurrence of 2 eclipses of the Moon, also observed at Babylon, and also recorded by Ptolemy.

639—546. *Thales*, of Miletus, founder of the Ionian School, and of Astronomy and Geometry in Greece.

610—547. *Anaximander*, of Miletus, an astronomical speculator.

600±. Mimnermus records the "myth" that the Sun after setting is carried round the Earth in a golden bowl until it is brought into view again in the East.

594. *Solon* "reforms" the Calendar, making it *less* accurate than it was before[c].

585. Occurrence of a solar eclipse, said to have been predicted by Thales.

[a] A very interesting Calendar of Astronomical Events, arranged under the various months of the year, from the pen of G. J. Walker, was published as a supplement to the *Ast. Reg.* for Sept. 1869.

[b] The first time an astronomer's name occurs it is printed in Italics. In this edition Star Catalogues are not as a rule noticed here, they having been dealt with more fully in Book XI than was formerly the case.

[c] How much like many modern reforms!

569—470. *Pythagoras*, founder of the School of Croton. He suspects the motion of the Earth, but leaves no writings.

545. Anaximander erects the first Sun-dial at Sparta.

540—500. *Xenophanes*, of Colophon, founder of the Eleatic School. He thinks that the heavenly bodies are luminous clouds.

525. *Anaximenes*, who considers that the Sun is *flat* like a leaf.

520—460. *Parmenides*, of Elea, who is said to have taught the sphericity of the Earth, and the identity of the morning and evening stars.

504. *Heraclitus*, of Ephesus, an astronomical speculator.

499—430. *Anaxagoras*, of Clazomenæ, geometer and active observer. Correctly explains eclipses, and is prosecuted for impiety.

490±. *Alcmæon*, of Croton, who states that the planets move from W. to E., or contrary to the stars.

469—399. *Socrates*, who discourages the study of astronomy, except so far as is necessary for the measurement of time and land.

459—360. *Democritus*, of Abdera, who writes on astronomical and mathematical subjects.

455. *Empedocles*, of Agrigentum, who writes on the constitution of the universe.

450. *Diogenes*, of Apollonia, who states that the inclination of the Earth's axis is intended to cause the seasons.

433. *Meton* erects the first Sun-dial at Athens.

432. Meton introduces the luni-solar period of 19 years.

424. Meton and *Euctemon* observe a solstice at Athens.

406. *Eudoxus*, of Cnidus, geometer and mathematician.

400. *Philolaus*, a distinguished disciple of Pythagoras, the first to commit to writing his master's opinions.

388. (d). *Theophrastus*, author of a history of astronomy. At about this time *Eudemus*, also an historical writer, flourishes.

384—322. *Aristotle*, writer on many physical subjects, including astronomy. The Humboldt of Greece.

370. Eudoxus introduces into Greece the year of 365¼ days.

330. *Calippus* introduces the cycle of 76 years as an improvement on Meton's. *Pytheas* measures the latitude of Marseilles, and points out the connexion between the Moon and the tides.

323—283. *Euclid* (the school-boy's enemy!), who writes on celestial phenomena, and also his well-known Elements of Geometry.

320–300. *Autolycus*, author of the earliest works on astronomy extant in Greek. About this time *Timocharis* and *Aristyllus* make those observations which afterwards enable Hipparchus to discover and determine the precession of the Equinoxes.

306. First Sun-dial erected at Rome by *Papirius Cursor*.

287—212. *Archimedes*, of Syracuse, who observes solstices, and attempts to measure the Sun's diameter: he is however more celebrated as a natural philosopher.

281. *Aratus*, of Cilicia, author of an interesting poem on astronomy, which has been translated into English verse by Lamb.

280. *Aristarchus*, of Samos, author of a work on the magnitudes and distances of the Sun and Moon.

276—196. *Eratosthenes*, of Syene, who determines with considerable accuracy the obliquity of the ecliptic, and also the latitude of Alexandria. A measure-

ment of an arc of the meridian between Syene and Alexandria, and other important observations are attributed to him.

260. *Manetho*, an Egyptian, author of a history now lost.

250 ±. *Conon*, of Samos, a celebrated astronomer.

220. *Apollonius*, of Perga, author of a treatise on Conic Sections and a planetary theory.

190—120. *Hipparchus*, possibly of Bithynia, the most distinguished of the Greek astronomers. He writes a commentary on Aratus; discovers the precession of the equinoxes; first uses Right Ascensions and Declinations, though afterwards abandons them for longitudes and latitudes; probably invents the stereographic projection of the sphere; determines the mean motion of the Sun and Moon with considerable exactness; suggests a method of determining the Sun's parallax; suspects that inequality of the Moon afterwards discovered by Ptolemy, and known as the Evection; calculates eclipses, and forms the first regular catalogue of stars, &c., &c. Altogether we may fairly call him the Newton of Greece.

135. (b?). *Posidonius*, of Apanea, who attempts to verify Eratosthenes's measure of the Earth. He alleges a connexion between the Tides and the Moon. His works are all lost.

50. *Sosigenes*, of Alexandria, in conjunction with Julius Cæsar, plans the Julian reform of the Calendar.

A.D.

10. *Manilius* writes a poem on astronomy and astrology.

50. *Seneca*, tutor to the Emperor Nero. He writes a work on natural philosophy, which contains many astronomical allusions, more especially to comets; these he surmises to be planets of some kind.

80. *Menelaus* writes treatises on spherical trigonometry, and makes observations at Rome and Rhodes.

117 (?). *Theon*, of Smyrna, makes observations at Alexandria, and writes on astronomy.

... *Cleomedes* writes on astronomy. It is, however, uncertain whether he lived before or after Ptolemy, though probably before.

117 (?). *Geminus*, about the same time as Cleomedes, writes on celestial phenomena.

100—170. Ptolemy, of Alexandria, a well-known observer and writer, author of the celebrated Μεγάλη Σύνταξις, called by the Arabians the *Almagest*. This work contains amongst other things a review of the labours of Hipparchus; a description of the heavens and the Milky Way; a catalogue of stars; sundry mechanical arguments against the motion of the Earth; notes on the length of the year, &c. To Ptolemy we owe the discovery of the Lunar Evection, and the refraction of the atmosphere, and a theory of the universe which bears his name.

173. *Sextus Empiricus* writes against Chaldean astrology.

238. *Censorinus* writes on astrology and chronology.

370. *Julius Firmicus Maternus* writes on astronomy.

383. *Pappus*, of Alexandria, writes a commentary on Ptolemy, all of which is lost.

385. *Theon*, of Alexandria, writes an able commentary on Ptolemy. He leaves some tables, and methods for constructing Almanacs.

415. *Hypatia*, daughter of Theon, the first female on record celebrated for her scientific attainments. Murdered in this year.

470. *Martianus Capella* writes a work called the *Satyricon*, which contains a few astronomical ideas. Amongst others, that Mercury and Venus revolve round the Sun.

500. *Thius*, of Athens, who makes some occultation observations, &c.

546. *Simplicius* writes a commentary on a work of Aristotle, now lost.

550. *Proclus Diadochus* writes a commentary on Euclid, and on the astrology of Aristotle, and shows the method of finding the meridian by equal altitudes.

636. *Isidore*, Archbishop of Hispalis (Seville), who writes on astronomy.

640. Destruction of the Alexandrian School of Astronomy by the Saracens under Omar.

720. *Bede*, who writes an astronomical work.

762. Rise of astronomy amongst the Eastern Saracens, on the building of Bagdad by the Caliph Al Mansur. Amongst this nation astronomy made great progress during the succeeding centuries.

814. The Caliph *Abdalla Al Mamoran*, who began his reign this year, caused measurements to be made in Mesopotamia with the view of arriving at an estimate of the dimensions of the Earth.

880. *Albategnius* or *Albatani*. The most distinguished astronomer between Hipparchus and Tycho Brahe. He discovers the motion of the solar Apogee, corrects the value of precession and the obliquity of the ecliptic; forms a catalogue of stars; first uses sines, chords, &c.

950. *Alfraganus* or *Al-Ferghani* and *Thalet Ben Korrah* both live about this time. The first writes on astronomy; and the second propounds a theory relating to the ecliptic.

1000. *Ebn Yunis* and *Abùl-Wefa* both live about this time. The former is an Egyptian astronomer of merit. He leaves a work containing tables and observations, which displays a considerable knowledge of trigonometry. He is the first to use subsidiary angles. Abùl-Wefa is the first to employ tangents, co-tangents, and secants, and is thought by some to have discovered the lunar inequality known as the Variation.

1020 (?). *Al-hanen* explains the law of atmospheric refraction.

1050. *Michel Psellus*. The last Greek writer on astronomy of note. *Alphetragius* devises an explanation of the motions of the planets.

1079. *Omar*, a Persian astronomer, proposes to reform the Calendar by interpolating 1 day every 4th year, postponing to the 33rd year the interpolation belonging to the 32nd. This would have produced an error of only 1 day in 5000 years: the Gregorian error is 1 day in 3846 years.

1080. *Arsachel*, a Spanish Moor, constructs some tables. *Alhazen* writes on refraction, and *Geber*, about this time, introduces the use of the co-sine, and makes some improvements in spherical trigonometry.

1200. *Abùl Hassan* forms a catalogue of stars, and makes some improvements in the practice of dialling.

About this time, or earlier, the Persians construct some tables which were translated by a Greek physician named *Chrysococca*, in the 14th century. The best known, however, are those of *Nasireddin*, published in 1270, under the patronage of Hulagu, grandson of Genghis Khan.

1220. *Sacrobosco* (Anglicè, *Holywood*) writes a work on the sphere, based on Ptolemy; he also writes on the Calendar. About this time *Jordanus* writes on the planisphere.

1230. About this year the *Almagest* is translated into Latin from the Arabic, under the auspices of Frederick II., Emperor of Germany.

1252. *Alphonso X.*, King of Castile, aided, as it is supposed, by certain Arabs and Jews, compiles the *Alphonsine Tables.*

1255. *Roger Bacon* writes on astronomy.

1280. *Cocheou-king* makes a number of good observations, and uses spherical trigonometry, under the patronage of Kublai, brother of Hulagu.

1433. *Ulugh Beigh*, grandson of Timour or Tamerlane, makes numerous observations at Samarkand, and is especially noted for his catalogue of stars. He also gives tables of geographical latitudes and longitudes.

1440. Cardinal *Cusa* writes on the Calendar, and, as some affirm, in favour of the Earth's motion.

1460. *George Purbach* publishes trigonometrical tables, and a planetary theory somewhat like that of Ptolemy.

1476. *John Müller*, better known by his Latin name *Regiomontanus*, writes an abridgment of the *Almagest*, and forms some extensive trigonometrical tables and the first Almanac.

1484. *Waltherus* uses a clock with toothed wheels.

1486. *George of Trebizonde*, called *Trapezuntius*, first translates the *Almagest* from the *Greek* into Latin.

1495. *Bianchini* publishes tables.

1504. (d.) Waltherus, a pupil of Regiomontanus, makes numerous observations.

1521. *Riccius* writes a treatise on astronomy, with especial reference to its history.

1528. (d.) *Werner*, who gave a more correct value of the precession of the equinoxes. *Fernel* gives a very correct measure of a degree on the meridian. Delambre remarks that it must have been accidental, seeing that his data were very imperfect.

1531. (d.) *Stoffler*, who wrote on the astrolabe and published Almanacs for 50 years.

1543. Publication of Copernicus's *De Revolutionibus Orbium Celestium*, in which is propounded his theory of the solar system, &c. The illustrious author dies in this year.

1552. (d.) *Apian*, who studied comets with great diligence. *Munster* writes on clocks and dials.

1553. (d.) *Rheinhold* (a friend of Copernicus), who constructed the *Prutenic Tables.*

1555. (d.) *Gemma Frisius.*

1556. Dr. *Dee* publishes a book on geometry.

1558. (d.) *Recorde*, said to have been the first modern English writer on astronomy and the sphere.

1571. (d.) *Leonard Digges*, author of *The Prognostication Everlasting*, and other works.

1572. Apparition of a new star in Cassiopeia, whose position is determined by *Hagecius*, by measuring the meridian altitude, and noting the time at which the observation was made.

1573. *Thomas Digges* proposes, as a means for determining the positions of celestial objects, the method of equal altitudes.

1576. (d.) *Rheticus*, editor of the *Opus Palatinum.*

1577. (d.) *Nonius*, inventor of an ingenious division of the circle now known as the "Vernier." Apparition of a comet upon which Tycho Brahe makes observations for the detection of parallax, in which he fails, thus shewing that comets traverse regions more removed from the Earth than the Moon.

1581. About this time *Galileo* remarks the isochronism of the pendulum.

1582. Tycho Brahe commences making observations in the island of Huenen, in the Baltic, near Copenhagen.

1592. (d.) The *Landgrave of Hesse Cassel*, a diligent amateur observer.

1594. (d.) *Gerard Mercator*, author of the projection of the sphere which bears his name.

1595. Thomas Digges, the son of Leonard Digges, publishes a work in this year.

1596. *Fabricius* discovers the variability of *o* Ceti.

1599. (d.) *Rothmann*, who observed comets. Publication of *Kepler's Mysterium Cosmographicum.*

1600. *Jordanus Brunus* is burnt to death at Rome for holding certain opinions on the system of the universe, for instance, that each star is a sun.

After the close of the 16th century, observers and observations begin to multiply so much, that henceforth we shall find it convenient to tabulate the principal astronomers of note, and then to give, in chronological order, an epitome of their labours. The dates are generally those of their deaths, but when that is not known, the date of the publication of some work is given in parentheses.

During the 17th century we have the following :—

Tycho Brahe	1601	De Rheita	(1645)
Scaliger, Jos.	1609	Crabtree	1645 ?
Clavius	1612	Fontana	(1646)
Calvisius	1615	Longomontanus	1647
Wright	—	Torricelli	—
Fabricius	1616	Descartes	1650
Napier	1617	Scheiner	—
Harriot	1621	Petavius	1652
Bayer	1625	Pascal	1653
Gunter	1626	Gassendi	1655
Snellius	—	Wing	(1661)
Briggs	1630	Lubienitz	(1668)
Malapertius	—	Riccioli	1671
Kepler	—	Borelli	1679
Vernier	(1631)	Dörfel	(1680)
Mœstlin	—	Picard	1682
Lansberg	1632	Hevelius	1687
Schickhardt	1635	Auzout	1693
Horrox	1641	Mercator, N.	1694
Galileo	1642	Bouillaud (Bullialdus)	—
Gascoigne	1644	Huyghens	1695

1603. Publication of *Bayer's* Maps of the Stars.

1604. Kepler succeeds in obtaining an approximate value of the correction for refraction. Apparition of a new star in Ophiuchus.

1608. *Hans Lippersheim*, of Middleburg, Holland, invents the refracting telescope, employing a convex object-lens.

1609. Galileo makes a telescope with concave eye-lens. Kepler publishes his work on Mars, in which he determines, by Tycho Brahe's observations, the elliptic form of its orbit, and ratio between the areas and the times, thus enunciating his 1st and 2nd laws.

1610. Galileo announces the discovery of Jupiter's satellites; of nebulæ; of some phenomena in connexion with the appearance of Saturn, afterwards found to proceed from the ring; the phases of Venus; the diurnal and latitudinal libration of the Moon. Harriot observes spots on the Sun.

1611. Foundation of the Lyncean Academy. Galileo and J. Fabricius observe spots on the Sun: the latter discovers its axial rotation.

1614. *Napier* invents logarithms.

1617. *Snellius* measures, by triangulation, an arc of the meridian at Leyden. This is the first recorded instance of the application of trigonometry to geodesy; the results are fairly correct.

1618. Kepler publishes his 3rd law.

1619. Snellius discovers the law of refraction from one medium into another.

1626. *Wendelinus* determines the diminution of the obliquity of the ecliptic; extends Kepler's laws to Jupiter's satellites; and ascertains the Sun's parallax.

1627. Kepler publishes his *Rudolphines Tables* based on the observations of Tycho Brahe.

1630. *Zucchi* observes the belts of Jupiter.

1631. *Gassendi* observes the first recorded transit of Mercury over the Sun; and measures the diameter of the planet. *Vernier* describes the instrument which bears his name.

1632. Publication of Galileo's *Dialogues*.

1633. *Norwood* measures an arc of the meridian between London and York. This is the first attempt of the kind in England. *Descartes* promulgates his "System of Vortices." Galileo is forced, by the bigotry of Romish ecclesiastics, to recant his Copernican opinions.

1635. *Morin* perceives stars in the day-time.

1637. *Horrox* suspects the long inequality in the mean motions of Jupiter and Saturn.

1638. Horrox ascribes the motion of the lunar apsides to the disturbing influence of the Sun, and adduces the oscillations of the conical pendulum as an illustration of the planetary movements.

1639. Horrox and *Crabtree* observe the first recorded transit of Venus over the Sun, and the former measures the planet's diameter. *Holwarda* notes the variability of *o* Ceti.

1640. *Gascoigne* applies the telescope to the quadrant, and the wire micrometer to the telescope.

1646. *Fontana* observes the belts of Jupiter.

1647. Publication of *Hevelius's Selenographia*, in which is announced the Moon's libration in longitude.

1650. Scheiner constructs a telescope with a convex object-glass.

1651. *Shakerley* observes a transit of Mercury at Surat, in the East Indies.

1654. *Huyghens* completes the discovery of Saturn's ring.

1655. Huyghens discovers that satellite of Saturn now known as Titan.

1656. Huyghens publishes his First Treatise on Saturn.

1657. Foundation of the Academia del Cimento at Florence.

1658 (or earlier). Huyghens makes the first pendulum clock.

1659. Huyghens, ignorant of what Gascoigne had previously done, invents a micrometer, and publishes a second treatise on Saturn. *Childrey* writes on the Zodiacal Light.

1660. *Mouton* applies the simple pendulum to observations of differences of Right Ascension, and by this means obtains a very good measurement of the Sun's diameter.

1661. Hevelius, at Dantzig, observes a transit of Mercury.

1662. Foundation of the Royal Society of London. *J. D. Cassini* begins his researches on refraction. *Malvasia* improves Huyghens's micrometer.

1663. *Gregory* invents the reflecting telescope which now bears his name.

1664. *Hooke* detects the rotation of Jupiter on its axis. J. D. Cassini observes the transit of the shadow of a Jovian satellite.

1665. Cassini determines the time of Jupiter's rotation, and publishes the first Tables of the Satellites. Hooke proposes the reticulated micrometer for the measurement of lunar distances. The Brothers *Ball*, at Minehead, detect the duplicity of Saturn's ring. Newton invents fluxions.

1666. Cassini determines the rotation of Mars and approximates to that of Venus. Foundation of the Academy of Sciences at Paris. *Auzout*, ignorant of Gascoigne's previous labours, applies the wire-micrometer to the telescope. *Newton* first directs his attention to the question of universal gravitation by considering whether the Moon might not be kept in its orbit by some force akin to terrestrial gravitation.

1667. Auzout and *Picard* apply the telescope to the mural quadrant, without knowing that Gascoigne had previously done the same thing. Some Fellow of the Royal Society proposes to employ the seconds' pendulum as an universal unit of length.

1668. Cassini publishes his Second Tables of Jupiter's Satellites, and Hevelius his *Cometographia*.

1669. Newton invents the reflecting telescope which now bears his name.

1670. Mouton first uses interpolations in observations.

1671. Picard and *La Hire* publish their degree of the meridian, obtained by measuring the arc between Paris and Amiens. *Richer*, in a voyage to Cayenne, observes the shortening of the seconds' pendulum as it is brought towards the equator. *Flamsteed* commences observations at Derby. Cassini begins the observations which lead to his discovery of the inclination of the Moon's equator. He also discovers that satellite of Saturn now known as Iapetus.

1672. Cassini discovers that satellite of Saturn now known as Rhea.

1673. Publication of Huyghens's *Horologium Oscillatorium*, in which are found the 5 theories relating to central forces and the first sound explanation of centrifugal force. Flamsteed explains the equation of time.

1674. Huyghens, ignorant of what Hooke has previously done, causes spring-watches to be made.

1675. *Römer* propounds his discovery relating to the transmission of light, as detected by observations on the phenomena of Jupiter's satellites. Foundation of the Royal Observatory, Greenwich. Römer applies the transit instrument to the determination of Right Ascensions.

1676. Flamsteed commences observations at the Royal Observatory, Greenwich.

1677. **Halley observes, at St. Helena, a transit of Mercury.**

1679. **Publication of Halley's Catalogue of Southern Stars. Commencement of the *Connaisance des Temps*.**

1680. **Flamsteed enunciates the law of the Moon's annual equation. Apparition of a celebrated comet, noticeable on account of its very small perihelion distance, and from its having led Newton to the opinion that comets moved in conic sections. Publication of Cassini's Lunar chart.**

1681. **Publication of *Dörfel's* work on Comets.**

1683. **Cassini and La Hire discontinue, till 1700, the arc of the meridian, commenced in 1680. Erection of a mural quadrant in the meridian at the Royal Observatory, Paris. Cassini investigates the Zodiacal Light.**

1684. **Cassini discovers those satellites of Saturn now known as Tethys and Dione.**

1687. **Publication of Newton's *Principia*.**

1689. **Römer uses the transit instrument for taking time. One Watson, an ingenious man at Coventry, makes the first Orrery, though the name is of later date, having been applied first to an apparatus made by G. Graham about 1700.**

1690. **Huyghens determines, theoretically, the ellipticity of the Earth. Publication of Hevelius's Catalogue of Stars.**

1693. **Cassini publishes his Third Tables of Jupiter's Satellites, and announces his discoveries on libration. Halley discovers the secular acceleration of the Moon's mean motion.**

1694. **Newton and Flamsteed commence their correspondence on the subject of the lunar theory and the theory of refraction.**

1700. **J. D. Cassini, aided by J. Cassini, extends southwards the arc, commenced by himself.**

The following is a list of the chief astronomers of note during the 18th century:—

Hooke	1703	Simpson, T.	1761
Römer	1710	Dollond	—
Cassini, J. D.	1712	Bradley	1762
Leibnitz	1716	La Caille	—
La Hire, P.	1718	Mayer, T.	—
La Hire, G. P.	1719	Bliss	1764
Flamsteed	—	Horrebow	—
Newton	1727	Clairaut	1765
Maraldi, J. P.	1729	Bird	(1766)
Bianchini	—	De L'Isle	1768
Manfredi	1739	Long	1770
Kirch	1740	Harrison	1776
Halley	1742	Ferguson	—
Hadley	1744	Lambert	1777
Maclaurin	1746	Zanotti	1782
Bernouilli, J.	1748	Wargentin	1783
Graham	1751	Lexell	(—)
Whiston	1755	D'Alembert	—
Cassini, James	1756	Euler	—
Fontenelle	1757	Cassini De Thury, F.	1784

Boscovich	1787	Du Sèjour	—
Maraldi, J. D.	1788	Pingré	1796
Palitzch	—	Rittenhouse	—
Lepaute, Mdme.	1789	Maraldi, J. P.	1797
Le Gentil	1792	Borda	1799
Bailly	1793	Le Monnier	—
Saron	1794	Cassini, Count	(1800)
Mudge	1794	Ramsden	—

1702. La Hire's researches on the theory of refraction.
1704. Römer commences star observations with a meridian circle.
1705. Halley predicts the return in 1759 of the comet of 1682.
1711. Foundation of the Royal Observatory, Berlin.
1714. J. Cassini discovers the inclination of the 5th satellite of Saturn.
1715. *Taylor's* researches on refraction.
1718. *Bradley* publishes his Tables of Jupiter's Satellites. J. Cassini and *J. P. Maraldi*, complete, at Dunkirk, the arc commenced by J. D. Cassini.
1719. Maraldi's researches on the rotation of Jupiter.
1721. Halley communicates to the Royal Society Newton's table of refractions.
1725. Publication of Flamsteed's *Historia Celestis*. Foundation of the St. Petersburg Observatory. *Harrison* announces the gridiron compensation pendulum.
1726. *Bianchini* determines the rotation of Venus. *Graham* invents the mercurial pendulum.
1727. Bradley discovers the aberration of light.
1728. Destruction, by fire, of Copenhagen Observatory, in which were stored the observations of Römer, and of *Horrebow* his successor, all of which are lost.
1729. *Bouguer* investigates the theory of refraction.
1731. *Hadley* invents the Sextant.
1732. *J. D. Maraldi* improves the theory of Jupiter's satellites. *Maupertuis* introduces into France Newton's theory. *Wright* publishes his Lunar Tables.
1736. Maupertuis, *Clairaut*, Le Monnier, and others measure an arc in Lapland, and Bouger and *La Condamine* one in Peru.
1737. *La Caille* and *Cassini* (III), re-measure the arc of J. D. Cassini. Clairaut improves the theory of the figure of the Earth.
1738. First experiment on the deviation of the plumb-line: at Chimborazo, and probably by Bouguer.
1739. Publication of *Dunthorne's* Lunar Tables.
1740. Publication of J. Cassini's Treatise on Astronomy, in which are given many new tables by himself and his father.
1743. Savary proposes the divided object-glass micrometer.
1744. Publication of *Euler's Theoria Motuum*, the first analytical work on the planetary motions.
1745. Bradley discovers the nutation of the Earth's axis. *Bird* commences his improvements in the graduation of instruments.
1746. Publication of Euler's Solar and Lunar Tables, and *Wargentin's* Tables of Jupiter's Satellites.
1747. Researches of Euler, Clairaut, and *D'Alembert*, on the theory of the planets. *Mayer* confirms by observation Cassini's theory of the lunar libration.
1748. Bouguer, unacquainted with Savery's discovery, proposes a double object-glass

micrometer, which he calls the heliometer. Publication of Euler's Essay on the Motions of Jupiter and Saturn.

1749. Investigations by Euler and D'Alembert on precession, by D'Alembert on nutation, and by Clairaut on the motion of the lunar apogee. Publication of Halley's Tables.

1750. Mayer introduces the use of equations of condition. *Boscovich* measures an arc of the meridian of Rimini. Publication of Wright's *Theory of the Universe*, in which is propounded that theory of the Milky Way afterwards adopted by Sir W. Herschel.

1751. La Caille goes to the Cape of Good Hope to commence a course of observations.

1752. La Caille measures an arc of the meridian at the Cape of Good Hope.

1754. Publication of Halley's Solar and Lunar Tables by *Chappe*; also of Clairaut's Lunar Tables.

1755. *Dollond* makes a divided object-glass micrometer. Mayer first suggests the idea of a repeating circle. Occurrence of a transit of Mercury.

1756. Researches of D'Alembert on the figure of the Earth; by Euler on the variation of the elements of elliptic orbits; and by Clairaut on the perturbation of Comets.

1757. Publication of La Caille's *Astronomiæ Fundamenta.*

1758. Publication of La Caille's Solar Tables. Re-invention by Dollond of the achromatic object-glass. Researches by Clairaut and *Lalande* on the orbit of Halley's comet.

1759. Publication of Halley's Planetary Tables by Lalande. Publication of an improved edition of Wargentin's Tables of Jupiter's Satellites.

1760. Bird's Standard Scale.

1761. *Maskelyne* at St. Helena. Transit of Venus.

1762. Researches by Euler and Clairaut on the perturbations of comets.

1764. Lalande confirms the observations of Mayer on the lunar libration. Publication of *La Grange's* prize essay on the same subject, containing the first application of the principle of virtual velocities. *Mason* and *Dixon* begin the measurement of an arc in Pennsylvania.

1765. Harrison obtains, after many vexatious delays, the reward promised by Parliament for the invention of the chronometer. J. D. Maraldi discovers the libratory motion of the nodes of Jupiter's second satellite.

1766. Publication by La Grange, and also by *Bailly*, of a theory of Jupiter's satellites.

1767. Commencement of the *Nautical Almanac.* Publication of Mayer's *Theoria Lunæ.* He invents the reflecting circle.

1768. *Beccaria* measures an arc of the meridian in Piedmont, and *Liesganig* in Hungary.

1769. Transit of Venus, which is very successfully observed, though the calculations derived from the observations have turned out to be affected by errors.

1770. Publication of Mayer's Solar and Lunar Tables. Discovery of Lexell's comet.

1771. Further researches by Bailly on Jupiter's satellites.

1772. Publication by *Bode* of *Titius's* law of planetary distances.

1773. Researches by La Grange on the attraction of spheroids; and by *Laplace* on the secular inequalities of the solar system.

1774. Experiments by Maskelyne on the Earth's attraction, on Mount Schehallien.

1777. *Rochon* invents the Rock-crystal Micrometer.

1780. Publication of Mason's Lunar Tables.

1781. *W. Herschel* discovers the planet Uranus. Publication of *Messier's* Catalogue of Nebulæ. (*Conn. des Temps*, 1784.) Wargentin discovers that the inclination of Jupiter's 4th satellite is variable.

1782. Laplace calculates the elements of the orbit of Uranus, and investigates the attraction of spheroids.

1783. Publication of *Nouet's* Tables of Uranus, and Pingré's *Cométographie.*

1784. Researches by Laplace on the stability of the solar system; on the relation between the longitudes of Jupiter's satellites; and on the great inequality of Jupiter and Saturn. *Roy* measures a base on Hounslow Heath for the connection of the observatories of Greenwich and Paris.

1786. Publication of Herschel's first catalogue of 1000 nebulæ (in *Phil. Trans.*). La Grange gives the differential equations for the variation of the elliptic elements. Borda invents his Repeating circle.

1787. Laplace's theory of Saturn's ring, and explanation of the acceleration of the Moon's mean motion. Herschel discovers 2 satellites of Uranus. *Le Gendre* and Roy complete the connection of the observatories of Greenwich and Paris. Commencement of the Trigonometrical Survey of England. Herschel commences observations with his 40-feet reflector, and discovers those satellites of Uranus now known as Oberon and Titania.

1788. Publication of La Grange's *Mécanique Analytique.* Herschel suspects that the motions of the satellites of Uranus are retrograde.

1789. Herschel determines the rotation of Saturn, and discovers the satellites Mimas and Enceladus. Publication of Delambre's Tables of Jupiter and Saturn.

1790. Herschel determines the rotation of Saturn's ring, and announces 2 new satellites of Uranus, which announcement has never been confirmed. Publication of Delambre's Tables of Uranus. *Brinkley* appointed director of the Dublin Observatory.

1792. Commencement of the Trigonometrical Survey of France. Publication of *Taylor's* Logarithms, Lalande's improved Planetary Tables, and *De Zach's* first Solar Tables. Madras Observatory founded by H. E. I. C.

1793. Laplace's researches on the satellites of Jupiter and the figure of the Earth. *Schröter* determines the rotation of Venus.

1795. Herschel's observations on variable stars, and the dismemberment of the Milky Way.

1796. Foundation of the French Institute of Science. Herschel suspects that the rotations of the satellites of Jupiter are of the same duration as their orbital revolutions. *Oriani* investigates the perturbations of Mercury.

1797. Delambre's observations on refraction. Laplace's theory of tides. *Olbers* publishes his method for determining the parabolic elements of a comet's orbit, since generally adopted by German astronomers.

1798. *Cavendish* demonstrates and measures the mutual attraction of metal balls. Herschel announces definitely that the satellites of Uranus move in a retrograde direction.

1799. Commencement of Laplace's *Mécanique Celeste.* Occurrence of a transit of Mercury. *Kramp's* researches on refraction.

The following is a list of the chief astronomers of note during the present century:—

Méchain	1804	Sheepshanks	1855
Lalande, J.	1807	Colla	1857
Cavendish	1810	Raper	1858
Maskelyne	1811	Bond, W. C.	1859
La Grange	1813	Wichmann	—
Messier	1817	Johnson	—
Burckhardt	—	Humboldt	—
Mudge	1821	Sonntag	1861
Herschel, Sir W.	1822	Daussy	—
Delambre	—	Biot	1862
Hutton	1823	Pape	—
Bode	1826	Jacob	—
Fraunhofer	—	Carlini	—
Piazzi	—	Mitchell, O. M.	—
Laplace	1827	Rümker, K. C.	—
Wollaston, W.	1828	Capocci	1863
Young	1829	Mosotti	—
Fallows	1831	Trettenero	—
Pons	—	Lehmann	—
Oriani	1832	Weisse	—
De Zach	—	Plana	1864
Groombridge	—	Struve, W.	1865
Le Gendre	1833	Bond, G. P.	—
Harding	1834	Gilliss	—
Troughton	1835	Smyth, W. H.	—
Kater	—	Encke	—
Brinkley	—	South, Sir J.	1867
Pond	1836	Wrottesley, Lord	—
Gambart	—	Rosse, Earl of	—
Moll	1837	Valz	—
Rigaud	1839	Foucault	1868
Olbers	1840	Dawes	—
Poisson	—	Ferguson	—
Bouvard	—	Herschel, Sir J. F. W.	1871
Littrow	—	Schwerd	—
Cacciatore	1841	Laugier	1872
Henderson	1844	Kaiser	—
Baily	—	Delaunay	—
Bessel	1846	Mrs. Somerville	—
Damoiseau	—	Schweitzer	1873
Di Vico	1848	Chacornac	—
Taylor	—	Donati	—
Schumacher	1850	Maury	—
Boguslawski	—	Quetelet	1874
Colby	1852	Mädler	—
Arago	1853	Hansen	—
Lindenau	1854	Pontécoulant	—
Petersen	—	Argelander	1875
Mauvais	—	D'Arrest	—
Gauss	1855	Winlock	—

1798—1804. *Humboldt* travels in America, and makes numerous observations.

1800. Bode's Maps and Catalogue. *Mudge* commences his great arc of the meridian, extending from the Isle of Wight to Clifton in Yorkshire. De Zach starts the *Monatliche Correspondenz*, which goes on for 12 years.

1801. *Piazzi* discovers the minor planet Ceres. *Svanberg* begins to measure an arc in Lapland.

1802. Olbers discovers the planet Pallas. Lambton begins the measurement of an arc in India.

1803. Publication of Herschel's Discovery of Binary Stars.

1804. *Harding* discovers the planet Juno. Piazzi publishes the proper motions of 300 stars. De Zach's Solar Tables.

1805. Le Gendre enunciates the method of least squares. Commencement of researches on Stellar Parallax by several observers.

1806. *Méchain* and Delambre complete the French Survey. Publication of Delambre's Solar Tables and Tables of Refraction; of Burg's Lunar Tables; of Carlini's Tables of Refraction. Herschel suspects the motion of the whole solar system towards the constellation Hercules. Publication of De Zach's Tables of Aberration and Nutation.

1807. Olbers discovers the planet Vesta. Extension of the French arc into Spain.

1808. Researches of La Grange and Laplace on the Planetary Theory.

1809. *Troughton's* improvements in the graduation of instruments. *Ivory's* Theorems on the Figure of the Earth. Publication of Gauss's *Theoria Motûs*.

1810. Groombridge's Refraction Tables. Carlini's Solar Tables. *Lindenau's* Tables of Venus. *Bessel* appointed director of the Observatory of Königsberg.

1811. Lindenau's Tables of Mars.

1812. Erection of Troughton's Mural Circle at Greenwich. *Burckhardt's* Lunar Tables.

1813. Lindenau's Tables of Mercury.

1814. Foundation of the Königsberg Observatory. Commencement of the *Zeitschrift für Astronomie*, which goes on till 1818.

1815. Bessel's researches on Precession.

1816. Lindenau assigns a new value to the constant of nutation. Poisson's researches on Planetary Perturbations.

1817. Delambre's Tables of Jupiter's Satellites. *Damoiseau's* researches on Halley's comet.

1818. Publication of Bessel's *Fundamenta Astronomiæ*. De Zach starts the *Correspondance Astronomique*, which goes on till 1825.

1820. Foundation of the Royal Astronomical Society of London. *Reichenbach's* meridian circle erected at Königsberg. Publication of Brinkley's Tables of Refraction. Commencement of the *Astronomische Nachrichten*, which valuable periodical is still in existence.

1821. Foundation of the Cape of Good Hope Observatory. Publication of *Bouvard's* Tables of Jupiter, Saturn, and Uranus. The practice of taking circle observations by reflection introduced at the Greenwich Observatory. Researches of Poisson on the Precession of the Equinoxes.

1822. Foundation of the Paramatta Observatory, N. S. W. *Argelander's* researches on the orbit of the comet of 1811.

1823. Foundation of the Cambridge Observatory. Researches by Ivory on Refraction. *Encke* suspects the existence of a resisting medium in space.

1824. Encke discusses the observation of the transits of Venus in 1761 and 1769 for the determination of the solar parallax. Erection of the Dorpat Refractor.

1825. Commencement of the *Berlin Zones*. Jones's mural circle erected at Greenwich.

1826. Researches of Bessel on the oscillation of the pendulum. Discovery of *Biela's* comet.

1827. The Royal Astronomical Society commences the publication of the *Monthly Notices*.

1828. *Airy* discovers a long inequality in the motions of Venus and the Earth. *Kater's* vertical collimator. Publication of Damoiseau's Lunar Tables (2nd ed.).

1829. Researches of Poisson on the attraction of spheroids, and of *Pontécoulant* on the orbit of Halley's comet.

1830. Publication of Bessel's *Tabulæ Regiomontanæ*.

1831. Publication of Plana's *Theory of the Moon*, vol. i.

1832. Occurrence of a transit of Mercury. Sir J. Herschel's investigation of the orbits of binary stars. *Don Joaquin de Ferrer* determines the solar parallax from a discussion of the observation of the transit of Venus in 1769.

1833. Airy obtains an important correction in the value of Jupiter's mass. Publication of the results of Lieut. *Foster's* pendulum experiments for determining the ellipticity of the Earth.

1834. Sir J. Herschel's researches on the satellites of Uranus. *Lubbock's* theory of the Moon.

1835. Encke commences his researches on Planetary Perturbation. Encke obtains a correction of the value of the solar parallax as deduced from the transits of Venus in 1761 and 1769. Airy determines the time of the rotation of Jupiter. Airy appointed Astronomer Royal. Researches of *Rosenberger* and *Lehmann* on Halley's comet.

1836. Publication of Baily's *Life of Flamsteed*. Publication of Damoiseau's Tables of Jupiter's Satellites.

1837. *Lamont's* researches on the satellites of Uranus. Researches by Pontécoulant on the Lunar Theory. *Henderson* determines the value of the Moon's equatorial parallax. Argelander's researches on the motion of the solar system in space. Completion of the great Indian arc of the meridian.

1838. Lubbock's researches on the Lunar Theory, Part ii. Bessel determines the parallax of 61 Cygni. *Hansen's* new method of investigating the Lunar Theory. *Robinson* determines the constant of nutation. Lamont determines the mass of Uranus.

1839. Commencement of *Le Verrier's* researches on the theories of the planets. Henderson determines the parallax of α Centauri. Foundation of the Imperial Observatory at Pulkova. Johnson appointed director of the Radcliffe Observatory, Oxford. *Amici's* double-image micrometer.

1840. Foundation of the Cambridge (U.S.) Observatory. Airy's double-image micrometer.

1841. Erection of Repsold's meridian circle at Königsberg. Researches of Hansen on the Lunar Theory.

1842. Foundation of the National Observatory, Washington (U.S.). *C. A. Peters* determines the constant of nutation; *Baily* determines the mean density of the Earth by a repetition of the Cavendish experiment.

1843. Hansen's new method of investigating the effects of planetary perturbation, whatever be the eccentricity or inclination of the orbit. *Schwabe* detects a periodicity in the solar spots. W. Struve determines the constant of aberration. *Adams* commences his investigation on the orbit of Uranus which ultimately leads to the discovery of Neptune. Le Verrier's theory of Mercury.

1844. *Sheepshanks* commences his researches to determine the length of the standard yard, which he continues till his death in 1855. Argelander concludes his northern hemisphere zone observations. Transmission of time by means of electric signals commenced in the United States. Publication of Smyth's *Cycle of Celestial Objects.*

1845. Discovery of a new minor planet Astræa: in subsequent years many others are detected. Researches of Le Verrier on the theories of Mercury and Uranus.

1846. Airy's measurement of the arc of parallel comprised between Valencia and Greenwich. Discovery of the planet Neptune. Publication of the results of the observations of the planets made at Greenwich between 1750 and 1830.

1847. Erection of the altazimuth at Greenwich. Hansen discovers 2 long inequalities in the Moon's motion. Publication of Sir J. Herschel's *Results of Astronomical Observations made at the Cape of Good Hope* in 1833 and following years; of W. Struve's *Études d'Astronomie Stellaire.* Researches of *Galloway* on the motion of the solar system. *Lassell* discovers the satellite of Neptune, and that satellite of Uranus since called Ariel, whilst O. Struve discovers Umbriel.

1848. Researches of *Challis* for determining the orbit of a planet or comet. Lassell in England and *W. C. Bond* in America discover independently the 8th satellite of Saturn, since called Hyperion. Researches of *Wichmann* on the physical libration of the Moon, and of C. A. F. Peters on stellar parallax.

1849. *Shortrede's* logarithms. Researches of *Powell* on irradiation. *Main* confirms the opinion of Bessel as to the strictly elliptical form of Saturn.

1851. Researches of C. A. F. Peters on the variability of the proper motion of Sirius. Pendulum experiments of *Foucault* for demonstrating the rotation of the Earth. Discovery of the dusky ring of Saturn. Erection of a new transit circle at Greenwich. Completion of the Russo-Scandinavian arc of the meridian. Dr. *Gould* starts in America the *Astronomical Journal. Oeltzen* commences the reduction of Argelander's zones, extending from 45° to 80° of north declination, which he finishes in the following year.

1852. Commencement of zone observations at the Cambridge (U.S.) Observatory. Researches of *Villarceau* on the orbits of double stars. Researches of *Secchi* on the Earth's temperature. Observations with the reflex zenith-tube commenced at Greenwich.

1853. Researches of Airy on ancient eclipses; of Adams on the secular inequality in the Moon's mean motion; of Hansen on the theory of the pendulum. Publication of the American Lunar Tables. Encke gives a new solution to the problem of Planetary Perturbation. Hansen's Solar Tables.

1854. The chronographic method of recording transits introduced at Greenwich. Researches of Lubbock on refraction. Airy's pendulum experiments in

the Harton Colliery for determining the density of the Earth. Determination of the difference of the longitude of Greenwich and Paris by electric signals.

1855. Researches of Main on the value of the constants of aberration and nutation, and on the rings of Saturn. Commencement of the publication of the *Annales* of the Paris Observatory, of the *American Nautical Almanac*, and of *Brünnow's Tables of Flora.*

1856. Researches of Challis on the problem of the 3 bodies; of Main on the diameters of the planets. Astronomical expedition to Teneriffe under *C. P. Smyth.*

1857. Researches of Airy on ancient eclipses. Publication of Hansen's Lunar Tables. *De La Rue*, Secchi, Bond, and others, obtain photographs of celestial objects. *Hoek's* investigation of the identity of the comets of 976 and 1556.

1858. De La Rue obtains a stereoscopic photograph of the Moon. Publication of Le Verrier's Solar Tables. Erection of a photoheliograph at the Kew Observatory. Occurrence of an annular eclipse which excited much interest in England. Donati's comet. Completion of the calculations for determining the principal triangles of the Trigonometrical Survey of the British Isles, and deduction of final results relating to the figure, dimensions, and density of the Earth.

1859. Completion of Le Verrier's theory of Mercury. Suspected discovery of a new planet revolving within the orbit of Mercury, and since named Vulcan. Numerous spots visible on the Sun during the summer months. Completion of the Berlin Star Charts commenced in 1830. Researches by Airy on the motion of the solar system.

1860. Erection of a fine achromatic Equatorial at the Greenwich Observatory. Occurrence of a total eclipse of the Sun visible in Spain, to observe which a large party of astronomers sail from England in H.M.S. *Himalaya*, besides other parties from France, &c.

1861. Discovery of many new planets. Apparition of 2 comets visible to the naked eye, of which the 2nd, which appeared in June, had the longest tail on record—105°. Le Verrier's theories of Venus and Mars.

1862. Lunar computations for the *Nautical Almanac*, conducted with Hansen's Tables. Publication of G. P. Bond's magnificent monograph on Donati's comet of 1858.

1863. Announcement by several computers that the received value of the solar parallax is too small by about $\frac{3}{10}''$. Researches by Airy and *Dunkin* on the motion of the solar system. Commencement of the *Astronomical Register*—the first English periodical exclusively devoted to astronomy. Spectrum observations of celestial objects by *Huggins* and *Miller*. Publication of Carrington's observations on Solar Spots.

1864. Balloon ascents by *Glaisher.*

1865. Important spectrum observations by Huggins, Miller, Secchi, and others.

1866. Apparition of a very striking temporary (or variable ?) star in Corona Borealis. Recurrence of a maximum in the November Periodic Meteors, which resulted in a display of remarkable beauty, attracting general public notice.

1867. Completion by *Cooke* for R. S. Newall of the largest object-glass yet made,

the diameter being 25 inches and the focal length 29 feet. Adams proves the identity of the November meteors with Tempel's comet.

1868. Important total eclipse of the Sun on August 18 visible chiefly in the East Indies. Red prominences observed on the Sun spectroscopically by *Lockyer* and *Janssen* independently and irrespective of the Sun being eclipsed. Publication of elaborate engravings of the great nebula in Orion by the Earl of Rosse and Mr. Lassell. Twelve minor planets discovered, the largest number ever found in any one year.

1869. Important total eclipse of the Sun on August 7, visible chiefly in North America. Experiments by the *Earl of Rosse* at Parsonstown, and by M. *Marie-Davy* at Paris, on the radiation of heat from the Moon.

1870. Total eclipse of the Sun on December 22 visible in Spain and Sicily; the expedition was conveyed in H.M.S. *Urgent.*

1871. Spectroscopic observations on the Sun by *Young*. Publication of *Williams's* Catalogue of Chinese comets. *Zöllner's* Reversion Spectroscope. Chronographic determination of the difference of longitude between London and Teheran through 3870 miles of wire.

1872. Researches by Huggins on the motions of Stars in the line of sight. Le Verrier's theory of Jupiter.

1873. Completion of *J. F. J. Schmidt's* Map of the Moon after 34 years' labour. Further researches by the Earl of Rosse on the radiation of heat from the Moon. Galle suggests observations of the minor planets for the determination of the Sun's parallax. *Newcomb's* tables of Uranus. Le Verrier's theory of Saturn.

1874. Coggia's comet. Transit of Venus on December 8, for which enormous preparations were made all over the world. Completion of Le Verrier's Planetary researches by the publication of the theories of Uranus (revised) and Neptune. Publication of *Cornu's* investigations respecting the velocity of light. The Royal Astronomical Society of London moves from Somerset House to Burlington House.

1876. Unprecedented absence of spots on the Sun.

BOOK IX.

METEORIC ASTRONOMY.

CHAPTER I.

Classification of the subject.—Aërolites.—Summary of the researches of Berzelius, Rammelsberg, and others.—Celebrated Aërolites.—Summary of facts.—Catalogue of Meteoric Stones.—Arago's Table of Apparitions.—The Aërolite of 1492.—*Of* 1627.—*Of* 1795.—*The Meteoric Shower of* 1803.

THE phenomena of which I am now about to speak form a highly interesting and by no means unimportant branch of descriptive astronomy. I shall treat of them under 3 heads:—

1. Aërolites.
2. Fireballs.
3. Shooting Stars.

Of all cosmical meteors those known as aërolites, meteorites, or meteoric stones, are the rarest, but nevertheless they are not so rare as to prevent satisfactory evidence being produced that such occurrences have happened from time to time. It is to Chladni that we owe much of our knowledge of this branch of the subject [a]. Many of these meteoric stones, which have fallen or been found in different parts of the world, have been subjected to chemical analysis by Berzelius, Rammelsberg, and others, whose deductions may be thus summed up:—

1. Meteoric stones are composed of elements all of which occur in terrestrial minerals.

2. Of the 65 elementary substances known, 24 have been found in meteoric stones, namely:—oxygen, hydrogen, chlorine, sulphur,

[a] See his work *Die Feuermeteore.*

phosphorus, carbon, silicon, iron, nickel, cobalt, chromium, manganese, copper, tin, antimony, aluminium, magnesium, calcium, potassium, sodium, lithium, titanium, arsenic, and vanadium.

3. The produce of a meteoritic shower may be divided into meteoric iron and meteoric stone.

4. Meteoric iron is an alloy that has not yet been certainly found to exist among terrestrial minerals, and is composed of iron with from 3 or 4 to 15 or 18 per cent. of nickel, and small quantities of cobalt, manganese, magnesium, tin, copper, and carbon.

5. Meteoric stone is composed of minerals found abundantly in lavas and trap-rocks (and consequently of volcanic origin), a variable proportion of meteoric iron being usually admixed.

The circumstances attending the fall of aërolites differ considerably on different occasions. Not unfrequently the fall is attended by a loud detonation; but we must not therefore infer that every detonating meteor is indeed an aërolite without positive proof to that effect. History records instances of considerable damage having been done to life and property by the descent of these bodies: as, for instance, from a Chinese catalogue we learn that one which fell on Jan. 14, 616 B.C., broke several chariots and killed 10 men. The chronicle of Frodoard informs us that in the year 944 A.D. globes of fire traversed the atmosphere and burnt several houses. More recently, on the evening of Nov. 13, 1835, a brilliant meteor was seen in the department of Ain (France). It traversed the country in a north-easterly direction, and burst near the castle of Lausères, setting fire to a barn and the stables, burning the corn and cattle in a few minutes. A stony substance supposed to be an aërolite was found near the place after the occurrence. On March 22, 1846, at 3 P.M., a luminous sheaf, which traversed the air with great velocity and noise, fell on a barn in a village in the department of Haute Garonne, which instantly took fire and was destroyed, together with the stables adjoining and the beasts therein contained[b]. It is related that the Emperor Jehangir had a sword forged from a mass of meteoric iron which fell at Jahlindù, in the Punjab, in 1620[c]. Some of these descriptions doubtless relate to veritable aërolites, but other alleged

[b] See Arago, *Ast. Pop.*, vol. iv. pp. 224–29, French ed., where numerous other instances are given. In the English edition this and other important meteor catalogues are unfortunately left out.

[c] *Phil. Trans.*, vol. xciii. p. 200. 1803.

instances of falls of aërolites are, it may be supposed, records merely of electrical discharges.

From the above and other similar observations we learn 3 things.

1. That the fact is undoubtedly established, that from time to time masses of stone, of different sizes, and often of considerable weight, pass through space, and are frequently precipitated upon the Earth's surface.

2. That these bodies do not always strike the Earth in a vertical or nearly vertical direction, although they almost always fall in a direction very oblique to the plane of the horizon. This is ascertained by an inspection of the manner in which they penetrate the Earth, which they often do to a considerable depth.

3. That they are originally endued with a very great velocity, bearing indeed a finite proportion to the velocities which are found to characterise the planetary members of the solar system. This velocity they soon lose, and by the time they reach the ground they possess little more velocity than that which appertains to them as bodies falling under the influence of gravitation.

The Ancients seem to have been well aware of the phenomena of which I am now treating, inasmuch as several objects are mentioned by the classic writers as having fallen from heaven: for instance, the Palladium of Troy, the image of Diana at Ephesus, and the sacred shield of Numa. The ideas of the Ancients relative to the supposed celestial origin of these things have often met with ridicule; but however fabulous the cases referred to may have been, still the Moderns have been compelled, though reluctantly, to admit the fact of the actual transmission of stony substances from Space on to the surface of the Earth. The following catalogue of some of the more important recorded falls of meteoric stones is founded on one given in M. Izarn's work[d].

Substance.	Period.	Place.
Shower of stones	About 650 B.C.	Rome.
Large stone	465 B.C.	River Negos, Thrace.
Three large stones..	452	In Thrace.
Shower of stones	343	Rome.
Shower of iron	54	Lucania.
Shower of mercury	Date unknown	In Italy.
Mass of iron of 14 quintals	„	Abakauk, Siberia.
Large stone of 260 lbs... ..	1492 Nov. 7 ..	Ensisheim, Upper Rhine.

[d] *Des Pierres Tombées du Ciel, ou Lithologie Astronomique.* Paris, 1803.

Substance.	Period.	Place.
About 1200 stones—1 of 120 lbs., another of 60 lbs.	1510	Padua, Italy.
Stone of 59 lbs.	1627 Nov. 27 ..	Mont Vasier, Provence.
Sulphurous rain	1646	Copenhagen.
Sulphurous rain	1658	Duchy of Mansfeld.
Shower of unknown matter	1695	Ireland.
Stone of 72 lbs.	1706 January ..	Larissa, Macedonia.
Shower of fire	1717 Jan. 4 ..	Quesnoy.
Shower of sand for 15 hours ..	1719 April 6 ..	In the Atlantic.
Shower of sulphur	1721 October ..	Brunswick.
Mass of stone	1750	Niort, Normandy.
Shower of stones	1753 July 3 ..	Plaun, Bohemia.
Two stones weighing 20 lbs. ..	1753 September	Liponas, in Brest.
Two stones of 200 and 300 lbs. ..	1762	Near Verona.
A stone of 7½ lbs.	1768 Sept. 13 ..	Lucé, Le Maine.
A stone	1768	Aire, Artois.
A stone	1768	Le Cotentin.
Shower of stones	1789 July ..	Barboutan, near Roquefort.
Extensive shower of stones	1790 July 24 ..	Near Agen.
About 12 stones	1794 July 16 ..	Siena, Tuscany.
A stone of 56 lbs.	1795 Dec. 13 ..	Wold Cottage, Yorkshire.
A stone of 10 lbs.	1796 Feb. 19 ..	In Portugal.
A stone of 20 lbs.	1798 March 12	Sales, near Ville Franche.
A stone of about 20 lbs.	1798 March 17	Sâle, dep. of Rhone.
Shower of stones	1798 Dec. 19 ..	Benares.
Mass of iron, 70 cubic feet	1800 April 5 ..	America.
Several stones, of from 10 to 17 lbs.	1803 April 26	Near L'Aigle, Normandy.
Shower of stones	1807 Dec. 14 ..	Weston, Connecticut, U. S.
A stone of 1653 lbs.	1810	Santa Rosa, New Grenada.
Shower of 200 stones	1812 May 22 ..	Stannern, Bohemia.
A stone of 203 lbs.	1821 June 15 ..	Juvinas, Ardéche.
A large stone	1843 Sept. 16 ..	Kleinwenden, Thuringia.
Shower of stones	1864 May 15 ..	Orgueil, France.
Stone of 6 cwt. and 1000 smaller ones	1866 June 9 ..	Knyahinya, Hungary.

The 206 falls of aërolites, of which Arago knew the month of occurrence, were, according to him, distributed in the following manner through the 12 months of the year:—

January	14	99	July	23	107
February	10		August	16	
March	22		September	17	
April	15		October	18	
May	20		November	20	
June	18		December	13	

From an inspection of the above table it appears that the

monthly average from December to June (16) is less than the monthly average from July to November (18), and that, moreover, the months of March, May, July, and November exhibit maximum numbers: and we also learn this general fact—that the Earth, in its annual course round the Sun, would seem to encounter a greater number of aërolites in passing from aphelion to perihelion, or between July and January, than in going from perihelion to aphelion, or between January and July.

It has been asserted to be a general rule that the area over which a shower of stones falls is oval, measuring from 6 to 10 miles in length by 2 or 3 in breadth, and, moreover, that the largest stones may be expected to be found at one extremity of the oval.

When found entire the stones are completely coated or glazed over with a thin dark-coloured crust formed from the molten substance of their surface fused by ignition in the fireball, the part which travelled foremost being sometimes distinguishable from that which was in the rear. Freshly-fractured faces have also been observed, and the pieces, 5 in number, of the well-crusted meteorite weighing 32 lbs. which fell at Butsura in India in 1861 were without difficulty fitted together by Maskelyne after an attentive consideration of the fractures. This is the more noteworthy from the fact that the pieces were picked up at places several miles apart. This instance of the disruption of a meteorite perhaps throws some light upon the circumstance that large fireballs are occasionally seen to break up into fragments as they disappear.

The circumstances connected with the occurrence which stands 8th in the catalogue on p. 782, are of more than ordinary interest, more especially from its having been long considered a poetical romance of by-gone ages. The following narrative was drawn up at the time by order of the Emperor Maximilian, and deposited with the stone in the church at Ensisheim. "In the year of the Lord 1492, on Wednesday, which was Martinmas Eve, November 7, a singular miracle occurred; for between 11 o'clock and noon there was a loud clap of thunder, and a prolonged confused noise, which was heard at a great distance; and a stone fell from the air, in the jurisdiction of Ensisheim, which weighed 260 pounds; and the confused noise was, moreover, much louder than here. There a child saw it strike on a field in the upper

jurisdiction, towards the Rhine and Jura, near the district of Giscano, which was sown with wheat, and it did no harm, except that it made a hole there; and then they conveyed it from that spot, and many pieces were broken from it, which the landvogt forbade. They therefore caused it to be placed in the church, with the intention of suspending it as a miracle; and there came here many people to see this stone. So there were remarkable conversations about this stone; but the learned said they knew not what it was; for it was beyond the ordinary course of nature that such a large stone should smite the Earth, from the height of the air, but that it was really a miracle of God; for, before that time, never anything was heard like it, nor seen, nor described. When they found that stone, it had entered into the Earth to the depth of a man's stature, which everybody explained to be the will of God that it should be found; and the noise of it was heard at Lucerne, at Vitting, and in many other places, so loud, that it was believed that houses had been overturned: and as the King Maximilian was here the Monday after S. Catherine's Day of the same year, his Royal Excellency ordered the stone which had fallen to be brought to the castle; and after having conversed a long time about it with the noblemen, he said that the people of Ensisheim should take it, and order it to be hung up in the church, and not to allow anybody to take anything from it. His Excellency, however, took two pieces of it, of which he kept one, and sent the other to Duke Sigismund of Austria; and they spoke a great deal about this stone, which they suspended in the choir, where it still is; and a great many people came to see it." This relic remained in the church for 3 centuries, and then it was temporarily removed during the turmoil of the French Revolution to Colmar, but it has since been restored. A fragment of it is in the British Museum, and there is another piece at the Jardin des Plantes, at Paris.

The fall of the aërolite of 1627 (No. 10) was witnessed by the astronomer Gassendi: he states that when in the air it was apparently surrounded by a halo of prismatic colours. This being the only aërolite of the fall of which he had ever heard, he supposed that it was the result of a volcanic eruption in some one of the neighbouring mountains. Views similar to Gassendi's of the origin of aërolites were maintained even recently by Kesselmeyer,

whose work on the geographical distribution of aërolites supplied an excellent list, with maps, of such occurrences up to a very recent date. Such views, it will not be necessary to remind the reader, cannot however now be held to accord with the known cosmical origin of these bodies.

The aërolite of Dec. 13, 1795 (No. 28), is interesting from the fact that it is one of the few instances recorded to have taken place in this country. A loud explosion, followed by a hissing noise, was heard through a considerable portion of the surrounding district; a shock was also noticed, as if produced by the falling to the Earth of some heavy body. A ploughman saw the stone fall to the ground at a spot not far distant from the place where he was standing; it threw up mould on every side, and, after passing through the soil, penetrated several inches deep into the solid chalk rock. It fell on the afternoon of a mild but hazy day, during which there was neither thunder nor lightning[e].

One of the severest falls of meteoric stones on record was that which happened in Normandy on April 26, 1803 (No. 34). It appears that at about 1 P.M. a very brilliant fire-ball was seen traversing the country with great velocity; and, some moments afterwards, a violent explosion was heard, which was prolonged for 5^m or 6^m. The noise seemed to proceed from a small cloud, which remained motionless all the time but at a great elevation in the atmosphere; the detonation was followed by the fall of an immense number of mineral fragments, nearly 3000 being collected, the largest weighing 8¾ lbs., according to Arago. The sky was serene, and the air calm—an atmospheric condition that has frequently been noticed, as well as opposite states of the weather, during the descent of aërolites[f].

[e] Howard, *Phil. Trans.*, vol. xcii. p. 174. 1802.

[f] A catalogue of 273 aërolites is given in Arago's *Ast. Pop.*, vol. iv. pp. 184–204, French ed. But larger numbers of aërolitic falls than this are now represented by specimens of meteorites preserved in the national museums of London, Paris, and Vienna; the British Museum alone possessing specimens of 307 different meteorites, of which nearly 200 were seen to fall. An article by Dr. Flight, in the *Geological Magazine*, 1875, contains a continuation of the list of Buchner and of other compilers, to the present time. The first such catalogue was formed by Chladni, and a larger one by Kämtz (*Meteorologie*). Subsequently Buchner (*Die Meteoriten in Sammlungen*), Haidinger, Rammelsberg, Mrs. Sheppard, U.S., and others have furnished catalogues, a collection and discussion of which by R. P. Greg will be found in the *British Association Report*, 1860, with later supplements and revised tables of frequency of aërolites on different dates, in the volumes for 1867 (p. 414) and 1870 (p. 93).

On April 20, 1876, a meteoric event of singular rarity took place in England, namely the fall of a mass of meteoric iron weighing between 7 and 8 lbs. at Rowton, near the Wrekin, in Shropshire. Shortly before 4 p.m. a sound like that of thunder followed by reports as of cannon shook the air, and was heard (during rain showers) for many miles in that neighbourhood, but no fireball was observed. The iron mass was found nearly an hour afterwards in a meadow where it had buried itself in the earth to a depth of 18 inches, and when dug out it was still quite hot.

This is only the seventh case where the actual fall of an aërosiderite or mass of meteoric iron has been observed, although many such masses have been found, some of them of large size, as at Krasnojarsk in Siberia, Atacama in Chili, Melbourne in Australia, and recently some colossal blocks on the Island of Disco in Greenland. At least one such meteoric mass has been discovered in this country, weighing about 32 lbs., which was exhumed near Melrose in Scotland in the year 1827; and previously to the present instance the following falls of meteoric iron have been observed:—Agram, Croatia (1751); Charlotte, Tenn., U. S. (1835); Braunau, Bohemia (1847); Victoria West, S. Africa (1862); Nidigullam, Madras (1870); Marysville, California (1873).

CHAPTER II.

FIREBALLS.

General description of them.—Fireball seen in 1861.—Arago's Table of Apparitions.—Results of calculations concerning particular fireballs.

FIREBALLS appear to hold an intermediate position between aërolites and shooting stars[a]. They appear suddenly, and after exhibiting a brilliant flame of light for a few seconds, as suddenly vanish. Their form is generally circular, or slightly oval, and of a perceptible magnitude. Not unfrequently they leave behind them a train of sparks, their own illuminating power being somewhat more feeble than that of the Moon. Sometimes they explode into fragments, which continue their course, or are precipitated, as we have already seen, upon the surface of the Earth in the form of aërolites.

The annexed figure represents a fine fireball seen on Nov. 12, 1861, in Herefordshire, by the Rev. T. W. Webb, whose account of it is as follows:—

"About 5^h 45^m G. M. T. (with an uncertainty of 5^m or more) we were walking, a party of 3 persons, along a wide turnpike road, fully lighted by a Moon 10 days old, when we were surrounded and startled by an instantaneous illumination, not like lightning, but rather resembling the effect of moonlight suddenly coming out from behind a dark cloud in a windy night; it faded very speedily, but on looking up we all perceived at a considerable altitude, perhaps 60° or 70°, a superb mass of fire, sweeping onwards and falling slowly in a curved path down the west-south-western sky. Its form was that of a pear, or, more precisely, an inverted balloon, and its size probably 30′ by 15′ at first, if not more; but it gradually diminished, and by the time it had attained the middle of its course may not have exceeded 20′ by

[a] In the opinion of Coulvier-Gravier aërolites are essentially different in their nature both from fireballs and shooting stars. This hypothesis has not met with general acceptance. (See chap. iv. *post.*)

10'. Its light was a beautiful blue, resembling, though far surpassing in vivid intensity, the hue of the asteroid Flora as we saw it many years ago, shortly after its discovery, with the 7-inch object-glass of the great telescope now at the Greenwich Naval School. Ruddy sparks, of the colour of glowing coals, were left behind at its smaller end, and its path was marked by a long pale streak of little permanency. Its termination, unfortunately, was concealed by boughs of trees, among which, however, it was traced till possibly some 10° above the horizon, but it had previously undergone a great diminution.

"Its general course was inclined 15° or 20° to the right of a vertical circle, but the angle progressively decreased, and must have been very small towards the last.

Fig. 268.

METEOR OF NOV. 12, 1861. (*Webb.*)

When first seen, it must have been near the body of Cygnus, and thence it followed, as nearly as could be estimated in so great a surprise and so strong a moonlight, the track of the west branch of the Galaxy, between Altair and Ophiuchus. The whole duration may have been as much as 5 seconds. Its aspect was decidedly that of a liquified and inflamed mass, and the immediate impression was that of rapid descent; but as its apparent magnitude diminished so much, with little comparative change of form, it is not improbable that it was in reality moving in a course not greatly inclined to the surface of the Earth [b]."

[b] Letter in the *London Review*, Nov. 16, 1861.

Arago, classifying all the apparitions of fireballs the dates of which were known to him, found that their number amounted to 813, distributed as follows:—

January	55	305	July	74	508
February	57		August	123	
March	48		September	64	
April	52		October	77	
May	50		November	90	
June	43		December	80	

Thus shewing that the periodicity which prevails with the aërolites also obtains with the fireballs, only in a much more marked manner.

Of the 813 fireballs referred to in the above table 35 only were accompanied by aërolites the fall of which was actually witnessed. Small though this proportion undoubtedly is, yet we cannot but consider these 2 classes of phenomena to be intimately associated. It is, however, true, that cases have been known in which aërolites have fallen, which were not preceded by any luminous exhalation: an instance occurred on Sept. 16, 1843, at the fall of the great aërolite of Kleinwenden[c].

Many fireballs have been submitted to measurement as regards their size and distance; but, owing to the very sudden appearance and in general the short visibility of these bodies, it seldom happens that the observer is able to attain to any great precision. The following results must therefore be received with caution.

1. As to the height at the instant of apparition.

Greatest known.	Miles.	Least known.	Miles.
1844 October 27	318·1	1846 March 21	7·5
1718 March 19	297·5	1852 April 2	10·0
1842 June 3	184·0	1754 August 15	15·0

2. As to absolute diameter.

Greatest known.	Feet.	Least known.	Feet.
1841 August 18	12,795	1852 April 2	105
1718 March 19	8,399	1846 July 23	321
1837 January 4	7,216	1850 July 6	705

[c] *Compt. Rend.*, vol. xxv. p. 627. Nov. 2, 1847.

3. As to velocity per second.

Greatest known.	Miles.	Least known.	Miles.
1850 July 6	47·22	1718 March 19	1·67
1844 October 27	44·74	1807 December 14 ..	2·80
1842 June 3	44·74	1676 March 31	3·11

The average velocity of 66 meteors, derived by A. S. Herschel from materials available up to the year 1863, is 34·4 miles per second.

It may be convenient to note here that the velocity of any part of the terrestrial equator due to the axial rotation of the Earth is 1521 feet per second, and that the Earth's orbital motion is 18·2 miles per second. We see, moreover, that the velocity of many of these fireballs is greater than that of any of the planets; it is also worthy of mention that the general direction of their motion is contrary to that of the Earth[d].

[d] A catalogue of 584 fireballs is given in Arago's *Ast. Pop.*, vol. iv. pp. 230–279, French ed. Special dates of annual frequency of aërolitic or detonating fireballs, and of bolides or silent meteors of the same class, are presented from more abundant materials than Arago's list contains, in the catalogue and supplements, and classified Tables of such appearances, by Mr. Greg, referred to on p. 786 *ante*. In the construction of such synoptic tables from very ancient records, it should be observed that the recorded dates (as was done by Prof. Newton for the dates of early star-showers) require to be advanced one day in 70 years to bring the dates converted when necessary from the old to the new style of reckoning, into proper correspondence with one and the same fixed equinox of the present time. The dates of frequency shown by the Tables, though depending as they do chiefly upon very modern observations, may yet be regarded as being in the main correct. A list of such dates and other interesting comparisons between the times of apparition of aërolites, fireballs, and shooting stars shown in the Tables are highly instructive as regards their possible distinction or connection, but to discuss the results that have thus been obtained would occupy too much space here.

CHAPTER III.

SHOOTING STARS.

Shooting stars.—Have only recently attracted attention.—To be seen in greater or less numbers almost every night.—Tabular summary of the results of the observations of Coulvier-Gravier and Saigey, and Schmidt.—Early notices of Meteoric Showers.—Shower of 1799.—Showers of 1831, 2, and 3.—The Meteors of 1833 divided into 3 groups.—The Shower of 1866.—Table of apparitions.—Singular result.—Olmsted's theory.—Herschel's theory.—Radiant points.

SHOOTING stars, although noticed in former times, have only within the last half century attracted any particular attention. This branch of the science may therefore be considered to be comparatively in its infancy. We must possess a long and carefully made series of observations before we are likely to be even moderately well acquainted with the physical nature of these objects. They were formerly considered to be merely atmospheric meteors, caused by the combustion of inflammable gases. This opinion has, however, lost all its force, and they are now recognised as bodies, which, although they become inflamed on coming in contact with the Earth's atmosphere, yet have their origin far beyond it.

It is now an established fact that there is no night throughout the year on which shooting stars may not be seen; and that, on an average, from 5 to 7 may be noticed on a clear night every hour[a]. These occasional meteors may be termed "sporadic," in

[a] One observer, single-handed, can only take account of $\frac{1}{5}$ of the sky visible to him, and sees but $\frac{1}{6}$ of all the meteors that appear above his horizon. Prof. Newton reckons this latter number to be, on an average, 30 per hour, and the number of meteors traversing the atmosphere of the whole globe, daily, to be $7\frac{1}{2}$ *millions*! Telescopic meteors he considers to be 40 times more numerous than those visible to the naked eye. *Silliman's Journal*, 2nd Ser., vol. xxxviii. p. 135, July 1864; vol. xxxix. p. 193, March 1865; vol. xli. p. 192, March 1866.

contradistinction to those swarms which appear at certain times of the year, and which are "periodic." There is, moreover, an *horary* variation in their number, and the minimum occurs at 6 P.M., the mean at midnight, and the maximum at 6 A.M., as shewn by the following table[b]:—

Hours P.M.	6–7.	7–8.	8–9.	9–10.	10–11.	11–12.
Mean number of meteors	3·3	3·5	3·7	4	4·5	5

Hours A.M.	12–1.	1–2.	2–3.	3–4.	4–5.	5–6.
Mean number of meteors	5·8	6·4	7·1	7·8	8	8·2

If we designate the numbers coming from the N., E., S., W., by those letters respectively, we find E. > 2 W., N. = S. nearly, and that E. + W. = N. + S.

The following table contains the monthly mean of the hourly number of shooting stars as assigned by 3 eminent Continental observers[c]:—

	MM. Coulvier-Gravier and Saigey.		M. Schmidt.	
January	3·6	3·4	3·4	4·0
February	3·7		?	
March	2·7		4·9	
April	3·7		2·4	
May	3·8		3·9	
June	3·2		5·3	
July	7·0	8·0	4·5	4·7
August	8·5		5·3	
September	6·8		4·7	
October	9·1		4·5	
November	9·5		5·3	
December	7·2		4·0	

Notwithstanding the discordances in the above results, both tables agree in shewing that there are more shooting stars in the 2nd than in the 1st half of the year—a coincidence which we have already seen holds good both with aërolites and fireballs.

[b] *Month. Not.*, vol. xvii. p. 147, March 1857; Coulvier-Gravier, *Récherches sur les Etoiles filantes*, p. 171.

[c] Quoted in Arago's *Pop. Ast.*, vol. ii. p. 505, Eng. ed.

This has also been confirmed by the observations recorded in the Chinese annals.

I now come to speak of the well-known and very beautiful showers of shooting stars seen at certain seasons in such great abundance[d]. One of the earliest notices we find in history of this phenomenon is by Theophanes the Byzantine historian, who relates that in November 472 A.D. the sky at Constantinople appeared to be on fire with flying meteors. Condé, in his history of the dominion of the Arabs, speaking of the year 902 A.D., states that in the month of October, on the night of the death of King Ibrahim-Ben-Ahmed, an immense number of falling stars were seen to spread themselves over the face of the sky like rain, and that the year in question was thenceforth called the "Year of Stars." In some Eastern Annals of Cairo it is related that: "In this year, in the month *Redjeb* [August 1029], many stars passed, with a great noise, and brilliant light;" and in another passage it says: "In the year 599, on Saturday night, in the last *Mokarrun* [Oct. 19, 1202], the stars appeared like waves upon the sky, towards the east and west; they flew about like grasshoppers, and were dispersed from left to right; this lasted till daybreak: the people were alarmed." It is also recorded that a remarkable display took place in England and France on April 4, 1095. The stars seemed "falling like a shower of rain from heaven upon the Earth," and an eyewitness, having noticed where an aërolite fell, "cast water upon it, which was raised in steam with a great noise of boiling." In the Chronicle of Rheims we read that the stars in heaven were driven like dust before the wind, and Rastel says that: "By the report of the common people in this kynge's time [William II] divers great wonders were sene: and therefore the kynge was told by divers of his familiars that God was not content with his lyvyng; but he was so wilful and proud of mind, that he regarded little their saying."

In modern times, the earliest shower of falling stars of which we have any detailed description is that of Nov. 13, 1799, which was visible throughout nearly the whole of North and South America: it was seen even in Greenland by the Moravian missionaries.

[d] Catalogues of such showers, by Newton, will be found in *Silliman's Journal*, 2nd Ser., vol. xxxvi. p. 145, July 1863, vol. xxxvii. p. 377, vol. xxxviii. p. 53, May and July, 1864.

Humboldt, then travelling with M. Bonpland, in South America, says:—

"Towards the morning of the 13th we witnessed a most extraordinary scene of shooting meteors. Thousands of bodies and falling stars succeeded each other during 4 hours. Their direction was very regular from North to South. From the beginning of the phenomenon there was not a space in the firmament equal in extent to 3 diameters of the Moon which was not filled every instant with bodies or falling stars. All the meteors left luminous traces, or phosphorescent bands behind them, which lasted 7 or 8 seconds."

Mr. Ellicott, an agent of the United States, at sea in the Gulf of Mexico, thus describes the scene:—

"I was called up about 3 o'clock in the morning, to see the shooting stars, as they are called. The phenomenon was grand and awful. The whole heavens appeared as if illuminated with sky-rockets, which disappeared only by the light of the Sun after daybreak. The meteors, which at any one instant of time appeared as numerous as the stars, flew in all possible directions, except from the Earth, towards which they were all inclined more or less; and some of them descended perpendicularly over the vessel we were in, so that I was in constant expectation of their falling on us."

The same observer also states that his thermometer suddenly fell 24°, and the wind changed from S. to N. W., whence it blew with great violence for 3 days. Meteoric showers were also witnessed in North America, in the years 1814, 1818, and 1819.

Fine meteoric displays took place in 1831 and 1832, in both cases on Nov. 13. Captain Hammond, of the ship *Restitution*, then in the Red Sea, off Mocha, thus describes the latter:—

"From 1 o'clock A.M. till after daylight, there was a very unusual phenomenon in the heavens. It appeared like meteors bursting in every direction. The sky at the time was clear, the stars and Moon bright, with streaks of light and thin white clouds interspersed in the sky. On landing in the morning, I inquired of the Arabs if they had noticed the above. They said they had been observing it most of the night. I asked if ever the like had appeared before. The oldest of them replied that it had not."

This shower was seen from Arabia, westward to the Atlantic, and from the Mauritius to Switzerland. Various descriptions of it and of the star showers were collected by Arago in a Memoir on shooting stars which will be alluded to again presently.

By far the most splendid display of shooting meteors on record was that of Nov. 13, 1833, and one which, from its recurring after so exact an interval of time, served to point out a periodicity in the phenomenon. It seems to have been visible over nearly the whole of the northern portion of the American continent, or, more

exactly, from the Canadian lakes nearly to the equator. Over this immense area a sight of the most imposing grandeur seems to have been witnessed. The phenomenon commenced at about midnight, and was at its height at about 5 A.M. Several of the meteors were of peculiar form and considerable magnitude. One was especially remarked from its remaining for some time in the zenith over the Falls of Niagara, emitting radiant streams of light. In many parts of the country the population were terror-stricken by the beauty and magnificence of the spectacle before them. A planter of South Carolina thus narrates the effect of the phenomenon on the minds of the ignorant blacks:—

"I was suddenly awakened by the most distressing cries that ever fell on my ears. Shrieks of horror and cries for mercy I could hear from most of the negroes of the 3 plantations, amounting in all to about 600 or 800. While earnestly listening for the cause I heard a faint voice near the door, calling my name. I arose, and, taking my sword, stood at the door. At this moment I heard the same voice still beseeching me to rise, and saying, 'O my God, the world is on fire!' I then opened the door, and it is difficult to say which excited me the most—the awfulness of the scene, or the distressed cries of the negroes. Upwards of 100 lay prostrate on the ground—some speechless, and some with the bitterest cries, but with their hands raised, imploring God to save the world and them. The scene was truly awful; for never did rain fall much thicker than the meteors fell towards the Earth; east, west, north, and south, it was the same [e]."

The meteors of which the above shower was composed seem to have been seen of 3 different kinds:—

1. Phosphoric lines, apparently described by a point. These were the most abundant; they passed along the sky with immense velocity, as numerous as the flakes of a sharp snow-storm.

2. Large fireballs, which darted forth at intervals across the sky, describing large arcs in a few seconds. Luminous trains marked their path, which remained in view for a number of minutes, and in some cases for half an hour or more. The trains were generally white, but the various prismatic colours occasionally appeared, vividly and beautifully displayed. Some of these fireballs were of enormous size; indeed, one was seen larger than the Moon when at its full.

3. Luminosities of irregular form, which remained stationary for a considerable time. The one above mentioned as having been seen at the Falls of Niagara was of this kind [f].

[e] Quoted in Milner's *Gallery of Nature*, p. 140.

[f] Quoted in Milner's *Gallery of Nature*, p. 141 (abridged).

Subsequent to 1833 the month of November was for some years distinguished by an unusual number of shooting stars; but none of the showers equalled that which I have just described, though those of 1866 and 1867 were extremely striking, the former one, perhaps, especially so.

Many circumstances combined to make the display of 1866 an unusually interesting one. In the first place it was possible to predict its occurrence with a good deal of certainty, and then again the rarity of the phenomenon, joined with the increasing interest felt by the general public in scientific matters, led to the exhibition of a considerable amount of (*temporary*) astronomical enthusiasm. For many days previously all who enjoyed the most moderate astronomical reputation were besieged with applications for premonitory information on the part of their less learned compeers, and in England at any rate it may certainly be affirmed that never was any celestial occurrence so widely and so perseveringly watched.

I examined for the purposes of this work a great number of accounts, the generally accordant characters of which were too plentifully recorded and are too well known to be here usefully repeated. The following letter, penned by Dawes, who observed the meteors in Buckinghamshire, furnishes us with a brief and clear description of most of the salient features of the shower, which were attentively watched and very similarly described by other competent observers:—

"Between midnight on the 13th and $14^h\ 13^m\ 10^s$ (G.M.T.), 2800 meteors were counted by myself and one assistant in the eastern hemisphere. Another assistant looking out to the West counted nearly 400 in an hour, but became so bewildered by 6 or 7 bursting out almost simultaneously, and this repeatedly, that the attempt to count more was given up. I have no doubt from what I saw myself in the western hemisphere, there must have been at least 700 visible in the 2¼ hours. Adding to these 75 which were seen before midnight, and we have upwards of 3500 in all, up to about a quarter past 2 in the morning.

"Some were brighter than Venus ever is; but none were at all comparable to several which appeared in 1832, Nov. 12, of which, however, I have never met with any good or particular account [g]."

Most of the reports of experienced observers who watched the

[g] *Ast. Reg.*, vol. iv. p. 306. Dec. 1866. In *Ast. Reg.*, vol. xiii. p. 271, Nov. 1875, Mr. Webb draws attention to Dawes's original observation of the meteors of Nov. 12, 1832, in the *Mem.* R. A. S., vol. viii. p. 76.

progress of the shower continuously concur in placing at about 3000 or 4000 the total number that they saw, and which they could have counted; though it should be stated that the staff of the Greenwich Observatory, as the result of a nicely pre-arranged subdivision of work, were able to count more than 8000.

The newspapers devoted much of their space to the subject, but of the letters by non-astronomical writers, which came under my notice, published or in MS., the following is a fair type:—

> "From $11^h\ 30^m$ till 2^h this morning we were much interested in watching the shooting stars; anything so beautiful I never saw, especially about 1^h, when they were most brilliant—"

and so on by the ream!

The shower was at its height in England from about $12^h\ 45^m$ to $1^h\ 45^m$ A.M., when the radiant-point in Leo had risen about 25° above the Eastern horizon. The position of this radiant-point, close to the small star *x* (Bode) Leonis in Leo's sickle, coincides identically with the position assigned to it "at *x* Leonis" by Professor Twining in his description of the great November star-shower of 1833. Before 4 o'clock A.M. the shower had almost or entirely disappeared. Its display was vertical over a meridian about 75° East of Greenwich, and it was accordingly confined to the Old World, no appearance of that year's November star-shower having been visible in America. But in the following year the conditions were reversed, and a shower scarcely less conspicuous than that of 1866 was seen in America on the morning of November 14th, 1867, which was invisible or only very partially observed (just before sunrise) in Europe. It was vertical over a meridian about 50° West from Greenwich, and presented nearly the same appearances as those of the shower in 1866; while it was at its height in the United States at about $4^h\ 30^m$ A.M., Washington Mean Time. The years 1868 and 1869 were also marked, as the year 1865 had been, by November star-showers of considerably less brilliancy than those of the two maximum years, 1866 and 1867, and the phenomenon afterwards waned rapidly, scarcely any signs of it continuing to be discernible after the year 1872.

Another meteor shower of great importance occurs annually on August 10. Public attention was first directed to that date by Marie Ignace Forster, of Bruges, in a work *The Perennial*

Calendar, published in London in 1829, and his diary even contained a note of its annual character as early as the year 1811. But it was not until A. Quetelet constructed in 1836 the first general catalogue of meteor showers, that the fact of its annual recurrence was fully recognised and established. The shower was independently expected and successfully observed by E. C. Herrick in the United States[h], and by Quetelet at Brussels, in the years 1836 and 1837; and it has since never failed to be annually recorded. Years of maximum and minimum brightness have occasionally been noticed, the year 1863 having been of the former, and the years 1862, and 1876, of the latter class, but meteors of this shower appear never to be entirely absent during the nights of August 9th to 11th in each year. Herrick regarded the position of the radiant-point as being near the cluster (χ) in the sword-hand of Perseus, and another position at B, C, Camelopardi was also noted by Sir John Herschel at Slough in the year 1840. Very little certainty has yet been reached in assigning the exact centre of divergence of this meteor shower, as the meteors proceed rather from a radiant area than from a fixed point; but the centre of the area is not far from η *Persei*, and it is on this account that the meteors of the shower were first named *Perseïds* by Schiaparelli in the year 1866. The example has been followed in designating other meteor showers by the constellations in which their radiant-points are situated; so that we have the *Leonids* and the *Andromedes* of November 14 and 27, the *Geminids* of December 12, *Quadrantids* of January 2, *Lyrids* of April 20, and the *Orionids* of October 18–20, besides many other less conspicuous, and less accurately determined annually recurring meteor showers. The annual recurrence of the January shower was noticed by Wartmann at Geneva in 1835–8, and its radiant-point was determined by Stillman Masters in America in January 1863; that of the April and also of the October shower was shown by Herrick, in America, in 1839, who also ascertained their radiant-points. The November shower of *Andromedes* has appeared at intervals since the close of the last century, and we owe to Herrick in 1838, and subsequently to Heis and Schiaparelli the best observations of its radiant-point previously to one of its cyclical returns in the

[h] *Silliman's Journal*, 1st Ser., vol. xxxiii. pp. 176 and 354.

year 1872. Like all the foregoing meteor showers, except the last, the *Geminids* are also *annually* recurrent, and this character was noticed and the radiant-point of the shower was determined simultaneously by Mr. Greg in England, and by Professor Twining in America, on December 12, 1863. Indications of periodicity and of early notices of years of maxima of these appearances have been sought for, with some success, in catalogues of meteor showers by Prof. Newton[i] and Prof. Kirkwood with the probable result announced by Kirkwood[k] that the meteors of April, October, and December revolve in periods respectively of 28½, 27½, and 29 years, while the January meteor ring has a probable period of about 13 years. Another meteor shower is found by Kirkwood to exhibit signs of periodical appearance, whose modern date of occurrence is between April 28 and May 1. It should be added that July 15 and 16 have been described by Capocci as days when shooting stars are particularly frequent. But these two last meteor showers have not been recently observed, and their radiant-points have not yet been determined.

Accurate observations of the Perseïds in the years immediately following those of their discovery were made at the continental observatories, and published in the *Astronomische Nachrichten* by Bessel, Erman, and other astronomers, chiefly in consequence of a suggestion made by Olbers to determine differences of longitude by means of accurate time and position observations of their points of disappearance. Many of the astronomical views concerning shooting stars adopted until the first predicted return of the November meteors in 1866–67, are due to a valuable memoir on these new acquisitions to the solar system by Olbers (in Schumacher's *Jahrbuch* for 1837), where in the place of orbits approximately circular like those conceived by Biot, and in the contemporaneous paper on shooting stars above referred to, by Arago, they are assumed to move rather in comet-like or very elongated orbits. The 33 year cycle of the November meteors was pointed out and thus explained by Olbers, who also ventured thereupon to predict a probable great return of the November meteors about the year 1867, which, as well as the grounds upon which his conjecture

[i] *Silliman's Journal*, 2nd Ser., vol. xxxvi. p. 145, July 1863.

[k] *Proceedings of the American Philosophical Society*, vol. xi. p. 299, March 4, 1870, and vol. xiii. p. 501, Nov. 21, 1873.

rested, was thoroughly verified by the event. Not only were longitude differences of some of the chief German observatories determined by this means to fractions of a second, but among the meteors doubly observed at distant places the real heights and sometimes the real velocities of their flights were ascertained—methods of computing which were given by Olbers, and most accurately by Bessel[l]. Orbits of the August meteors were calculated from such results by Erman, and some attempts were made (with only partial success) to obtain a true theory of this meteor ring from actual observations. But with the introduction and progress of more effective means of finding longitudes these August meteor observations ceased, and a period of many years was allowed to elapse before a fresh interest in the subject of meteor showers was awakened, as has been above related, by the punctual reappearance with its anticipated brilliancy of the expected shower of Leonids in November 1866.

Subdividing the recorded instances of great showers of shooting stars according to the months of the year, we obtain the following results:—

January	10	55	July	14	166
February	10		August	56	
March	12		September	13	
April	17		October	29	
May	4		November	37	
June	2		December	17	

We thus find, and it is worthy of especial remark, that the coincidence to which I have already adverted in the case of aërolites, fireballs and sporadic meteors also obtains with the showers of shooting stars — namely, that the Earth encounters a larger number of these bodies in passing from aphelion to perihelion, or between July and January, than in passing from perihelion to aphelion, or between January and July[m].

In the opinion of Coulvier-Gravier the more numerous shooting stars are, the more rainy the weather is. With the exception of the daily and hourly rates of frequency, the relative numbers of

[l] *Ast. Nach.*, vol. xvi. No. 380. July 25, 1839.

[m] A catalogue of 221 meteoric showers is given in Arago's *Ast. Pop.*, vol. iv. pp. 292–314. Also a catalogue, extending from 538–1223 A.D., by Chasles, in *Compt. Rend.*, vol. i. pp. 499–509. 1841. For an account of Quetelet's Catalogue see p. 807, *post*.

meteors of different brightnesses (or with crooked paths, and leaving streaks, &c.), described in his work *Recherches sur les Météores* from nearly 50 years' continued observations, little of astronomical consequence can be gathered from the general results; all the meteor courses therein finally included being simply classed like winds by the points of the compass towards or from which they were directed. It is greatly to be regretted that the valuable records by M. Coulvier-Gravier, extending from 1811–55 and continued to the present time at the Luxembourg Observatory, Paris, by his successor M. Chapelas Coulvier-Gravier, with accurate astronomical details of all the meteor courses mapped and registered, should still remain unpublished. Their scientific value, if published, could not fail to be considerable.

CHAPTER IV.

THE THEORY, ETC. OF METEORS.

Meteors probably planetary bodies.—Their periodicity.—Their orbits.—The great November showers of Shooting Stars probably caused by a mass of Meteors which revolve round the Sun in about 33 years.—The investigations of H. A. Newton.—Of Adams.—Supposed connection between Meteors and Comets.—Recent progress of Meteoric Astronomy.

ARE we entitled to consider those objects which we call aërolites, fireballs, and shooting stars as various manifestations of one and the same class of bodies, or are they distinct and separate phenomena? These are difficult questions to answer confidently. The current of popular opinion amongst men of science has for some years run in the direction of identity, and I think we shall not do wrong by assuming this; at any rate no serious practical inconvenience will arise from our disregarding in the present chapter evidence of contrary import.

Many have been the theories propounded as to luminous meteors. The recital of even the least absurd would be of no advantage to the reader; I therefore proceed to state that one theory to which alone credit is now attached.

It is supposed that meteors are planetary bodies; that they revolve round the Sun in orbits, the form of which will be discussed presently; that these orbits intersect at times the annual path of the Earth; that when the Earth passes through the point of intersection of its path with their orbits, they either encounter it directly and fall upon its surface, or, entering its atmosphere, are

rapidly retarded by the resistance of that fluid and are drawn to the surface by terrestrial attraction; that the meteors denominated shooting stars and fireballs are such as are ignited on entering and consumed before they have penetrated far into, whilst aërolites are meteors which succeed in effecting a passage entirely through the Earth's atmosphere to the Earth's surface.

With the meteors there prevails, as we have already seen, a periodicity: this will be found on examination to countenance the theory of their being planetary in their nature, and the well-known experiment of igniting tinder by compressing air in a fire syringe removes the notion of self-ignition from the domain of fanciful speculation.

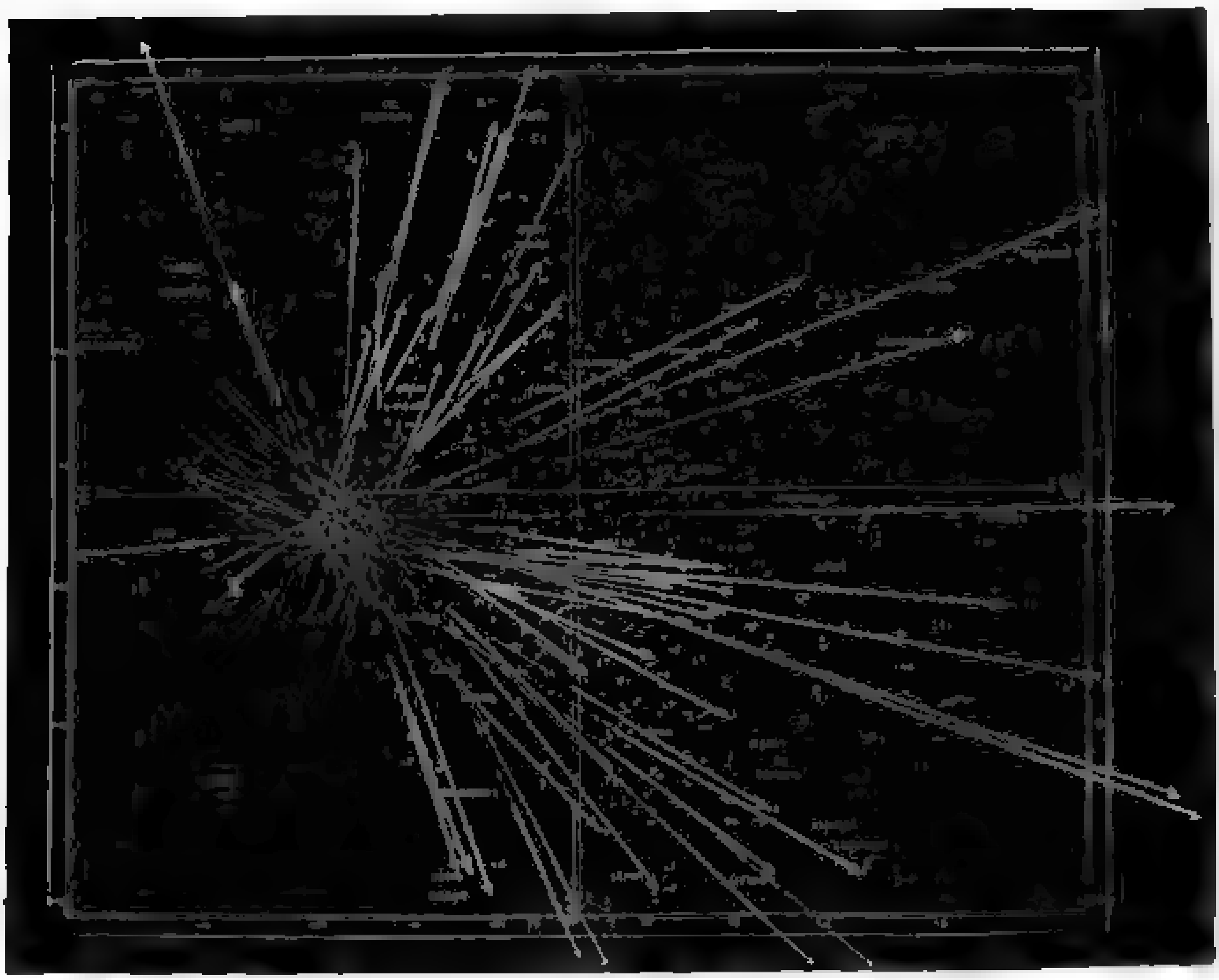
With reference to their periodicity, Sir J. Herschel says:—

"It is impossible to attribute such a recurrence of identical dates of very remarkable phenomena to accident. Annual periodicity, irrespective of geographical position, refers us at once to the place occupied by the Earth in its annual orbit, and leads directly to the conclusion that at that place it incurs a liability to *frequent* encounters or concurrences with a stream of meteors in their progress of circulation around the Sun. Let us test this idea, by pursuing it into some of its consequences. In the first place, then, supposing the Earth to plunge in its yearly circuit into a uniform ring of innumerable small meteoric planets, of such breadth as would be traversed by it in one or two days; since, during this small time, the motions, whether of the Earth or of each individual meteor, may be taken as uniform and rectilinear, and those of all the latter (at the place and time) parallel, or very nearly so, it will follow that the relative motion of the meteors, referred to the Earth as at rest, will be also uniform, rectilinear, and *parallel*. Viewed, therefore, from the centre of the Earth (or from any point of the circumference, if we neglect the diurnal velocity, as very small compared with the annual), they will all appear to diverge from a common point, *fixed in relation to the celestial sphere*, as if emanating from a sidereal apex.

"Now this is precisely what happens. The meteors of the 12th–14th of Nov., or at least the vast majority of them, describe apparently arcs of great circles, passing through or near γ Leonis. No matter what the situation of that star, with respect to the

horizon or to its East and West points, may be at the time of observation, the paths of the meteors all appear to diverge from that star. On the 9th–11th of August, the geometrical fact is the same, the apex only differing; B Camelopardi being for that epoch the point of divergence. As we need not suppose the meteoric ring coincident in its plane with the ecliptic, and as for a *ring*

Fig. 269.



THE METEOR RADIANT POINT IN LEO:
TRACKS OF METEORS SEEN AT GREENWICH, NOV. 13, 1866.

of meteors we may substitute an elliptic annulus of any reasonable eccentricity, so that both the velocity and direction of each meteor may differ to any extent from the Earth's, there is nothing in the great and obvious difference *in latitude* of these apices at all militating against the conclusion.

"If the meteors be uniformly distributed in such a ring or elliptic annulus, the Earth's encounter with them in every revolution will be certain, if it occur once. But if the ring be broken —if it be a succession of groups revolving in an ellipse in a period *not* identical with that of the Earth, years may pass without a rencontre; and when such happen, they may differ to any extent in their intensity of character, according as richer or poorer groups have been encountered.

"No other plausible explanation of these highly characteristic features (the annual periodicity and divergence from a common apex, *always alike for each respective epoch*) has been ever attempted, and, accordingly, the opinion is generally gaining ground among astronomers, that shooting stars belong to their department of science, and great interest is excited in their observation, and the further development of their laws[a]."

We come now to discuss the orbits in which meteors (assumed to be small planets or something of the sort) circulate round the Sun. Fig. 270 will serve to convey an idea of the theory in the form in which it was first broached[b]. The meteors are regarded as infinite in number and revolving around the Sun at a distance about the same as that of the Earth in orbits nearly circular but so disposed as to cut the orbit of the Earth. Obviously, cutting the Earth's orbit at all, they must do so twice, and the relative distance between the two points of intersection corresponds to the space traversed by the Earth between August 10 and Nov. 13. Slightly extended, the theory propounded a gathering together of the meteors into several rings, having orbital characteristics somewhat different *inter se*, a modification of the original idea conceived to be necessary on account of meteors being visible at other seasons of the year besides those above named.

But another planetary theory of a much more comprehensive character has now to be unfolded.

In November, 1833, there was witnessed, as has already been stated, a grand display of meteors ("shooting stars"), a less grand one in 1832, and 33 years before that, namely in 1799, another very magnificent one. Availing himself of a comprehensive

[a] *Outlines of Ast.*, p. 661.

[b] By Biot, and Arago. The valuable Memoirs on Shooting Stars containing the often-quoted views of these astronomers appeared in the *Comptes Rendus*, 1835, p. 393, and 1836, p. 663.

catalogue of recorded appearances of meteor showers compiled by A. Quetelet in 1836–39[c], a learned American astronomer, Prof. H. A. Newton, set himself the task[d] of searching out all the ancient records he could find of such displays: he found that more than a dozen had been taken note of by historians, beginning with 902 A.D., and that in all cases the intervals were either $\pm \frac{1}{3}$rd of a

Fig. 270.

DIAGRAM ILLUSTRATING THE THEORY THAT AËROLITES ARE SMALL PLANETS REVOLVING ROUND THE SUN.

century or some multiple of that period. This was too important a fact to be neglected. By a course of reasoning, the several steps of which I do not deem it necessary to reproduce, Newton concluded

[c] *Nouveaux Mémoires de l'Académie Royale des Sciences*, vol. xii. 1839.

[d] His papers appear in *Silliman's Journal*, 2nd Ser., vol. xxxvii. p. 377, and vol. xxxviii. p. 53, May and July 1864. The periodic dates of the November and of some other annual meteor showers had been discussed in a previous paper in the same *Journal*, vol. xxxvi. p. 145, July 1863.

that the ± 33 year visible periodicity was only reconcileable with an orbit whose period was either 180^d, $185{\cdot}4^d$, $354{\cdot}6^d$, $376{\cdot}6^d$, or $33{\cdot}25^y$. Why the true period *must* be one of these 5 involves mathematical considerations unsuitable to these pages. The period chosen by Newton himself as the most probable was the $354{\cdot}6^d$ one, corresponding to an orbit nearly circular; but he pointed out that a certain retardation of the date which has taken place can only be explained by assigning to the meteor orbit that one of the 5 possible forms which is able to account for the retardation, and that a proper mathematical calculation undertaken for this purpose would finally decide which of the five forms is the real one. With these remarks on the orbit, and with a prediction that another great display would occur on the morning of the 14th of November, 1866, Newton terminated his investigations.

If the period had been exactly one year, the meteors would appear once a year, but the theory of a period of 354^d implies that, if we reckon from any one year of coincidence of place, when the Earth arrived at the same point of its orbit in the following year, the meteors (which Newton conceived to be disposed in a *group* which occupies $\frac{1}{10}$ to $\frac{1}{15}$ of the periodic time in passing any given point, and not in a ring) would be 11 days behind; and that it was the successive falling short of 11 days every year which, accumulating, brought round a coincidence every 33rd year $\pm$: for (taking approximate figures)—

$$365 \div 11 = 33{\cdot}2.$$

In April, 1867, Prof. Adams presented to the Royal Astronomical Society an outline of a very important investigation* which, proceeding on Professor Newton's suggestion, he had brought to a satisfactory conclusion. Availing himself of Newton's labours, he sought to arrive at some more precise knowledge of the orbit of the November meteors, taking advantage, of course, of the information furnished by the observations made in November 1866. I should premise that Newton's inquiries shew that the display which in 1866 happened on Nov. 13, in 902 happened on Oct. 12 (o. s.), indicating a progressive increase in the longitude of the points of intersection of the orbits of the meteors and the Earth. The amount of this motion is $102{\cdot}6''$ annually with respect to the

* *Month. Not.*, vol. xxvii. p. 247. April, 1867.

Equinox or of 52·6″ with respect to the stars, equal to 29′ in 33¼ years. Adams calculated the extent of the progressive increase due to the perturbing influence of the planets Venus, Jupiter, and the Earth. He found that their conjoint effect, on the assumption that the period of the meteors was 180^d or 185^d or 354^d or 377^d, in no case exceeded 12′ in 33¼ years, but that assuming 33¼ years to be the period, planetary influence (in this case caused by Jupiter, Saturn, and Uranus) would produce an increase of 28′. The near coincidence of this theoretical 28′ with the observed 29′ places it almost beyond doubt that the true period is 33¼ years. Proceeding on this assumption, and having found that, according to the mean of several estimations, the radiant point of the 1866 meteors was situated in—

R.A.	Decl.
h. m.	° ′
9 56	+ 23 1

Adams proceeded to calculate elliptic elements of the orbit of the meteors, and he obtained the following set:—

Period	=	$33{\cdot}25^y$ (assumed)
Mean distance	=	10·3402
Eccentricity	=	0·9047
Perihelion distance	=	0·9855
		° ′
Inclination	=	16 46
Longitude of Node	=	51 28
Distance of Perihelion from Node	=	6 51
Heliocentric motion	..	Retrograde.

With this our discussion of meteoric orbits might terminate, but something else has to be said on another subject which seems to awaken a remarkable degree of interest in regard to the entire question of meteors.

It has been pointed out that the above elements so strikingly resemble those of comet i. 1866 as to render it almost certain that some relation subsists between that comet and the meteors of the following November.

The elements of that comet, arranged for convenience of comparison, in the form adopted above in the case of the meteors, are as follows:—

Period	=	$33{\cdot}18^y$
Mean distance	=	10·3248
Eccentricity	=	0·9054
Perihelion distance	=	0·9765

		°	′
Inclination	=	17	18
Longitude of Node	=	51	26
Distance of Perihelion from Node	=	9	2
Heliocentric motion		Retrograde.	

That the close accord here shewn is not accidental may be considered to be certain.

But this coincidence does not stand alone. Schiaparelli has shewn that a similar accord subsists between the elements of the orbit of the August meteors and those of comet iii. 1862, whilst Weiss and Galle have discovered that the same is true of the meteors of April 20 and comet i. 1861[f]. A no less remarkable accordance than that of the Leonids and Tempel's comet was also remarked by the last-named astronomers, and by D'Arrest[g] between the orbit of Biela's double comet and meteor showers of some importance recorded on the 5th, 6th, and 7th of December, 1741, 1798, 1830, and 1838, and apparently with the same radiant-point in the East part of Andromeda towards the end of November in some later years. The expected return of Biela's comet in August and September, 1872, afforded an opportunity for verifying the presumed connection; and the appearance of an abundant (although not extremely brilliant) star shower agreeing identically in the position of its radiant-point and in the date of its appearance with those of a meteor stream following directly in the track of Biela's comet (about 12 weeks after the comet's departure from the place), on November 27, 1872, corroborated afresh an inference already drawn from the three previously known examples of agreement, that a considerable maximum assemblage of the meteors revolving with a cometary body *follows* in its orbit very closely the body of the comet. A somewhat different surmise from this conjecture is however suggested by the showers of Andromedes seen in the years 1798, 1830, and 1838, which must have *preceded* Biela's comet at different distances between $\frac{1}{20}$ and $\frac{1}{3}$ of a revolution along its track. A separate group of the Leonids is also suspected to exist, preceding the principal one about 12 years (or about $\frac{1}{3}$ of a revolution) in its appearance. Notable star

[f] *Ast. Nach.*, vol. lxviii. No. 1632, March 9, 1867; vol. lxix. No. 1635, Apr. 2, 1867; see also a paper by Lynn, *Proc. Meteorological Soc.*, Apr. 17, 1867; and papers by Weiss, *Ast. Nach.*, vol. lxxii. No. 1710, Aug. 25, 1868, and *Sitzungsberichte der Acad. der Wissenschaften*, Vienna, vol. lvii. p. 281, 1868.

[g] *Ast. Nach.*, vol. lxix. No. 1633, March 19, 1867.

showers are recorded to have taken place in 855-56, 1787, and 1818-23, and finally by Prof. D. Kirkwood in 1852, agreeing exactly with the principal cluster in the day, and very closely also in the period of their returns[h]. The original dismemberment of the comet, to which the ancient record of this widely distant cluster points, must have been of extraordinary antiquity, since the interval of 12 years between the years 855-56 and the next principal Leonid display in 868 differs scarce sensibly from the distance still found to separate the two clusters from the well-marked minor apparitions of the years 1787, 1820, and 1822 compared with the modern appearances of the chief cluster in 1799 and 1833. It is thus that highly important consequences may be expected to be traced from these and similar investigations and discussions, indeed, the subject may perhaps fairly be deemed an inexhaustible one, for a few coincidences having been ascertained, more will be sure to follow as observations multiply and research extends.

As to the nature of the connection between comets and meteors (the bare fact of which cannot now be called in question) it is at present premature to speculate, but it would seem that we are on the eve of some highly important discovery, the skeleton of which may be that a comet is capable, under some circumstances at present unknown to us, of throwing off into space numbers of entities which reveal themselves to us as shooting stars.

There seems some reason for believing that the number of shooting stars visible both in August and November is subject to a periodical variation, the duration of which is at present unknown. It may be added that a French physicist considers himself warranted in asserting from some inquiries which he has conducted, that the prevalence of shooting stars coincides with *and causes* [?] an increase in the temperature of the weather.

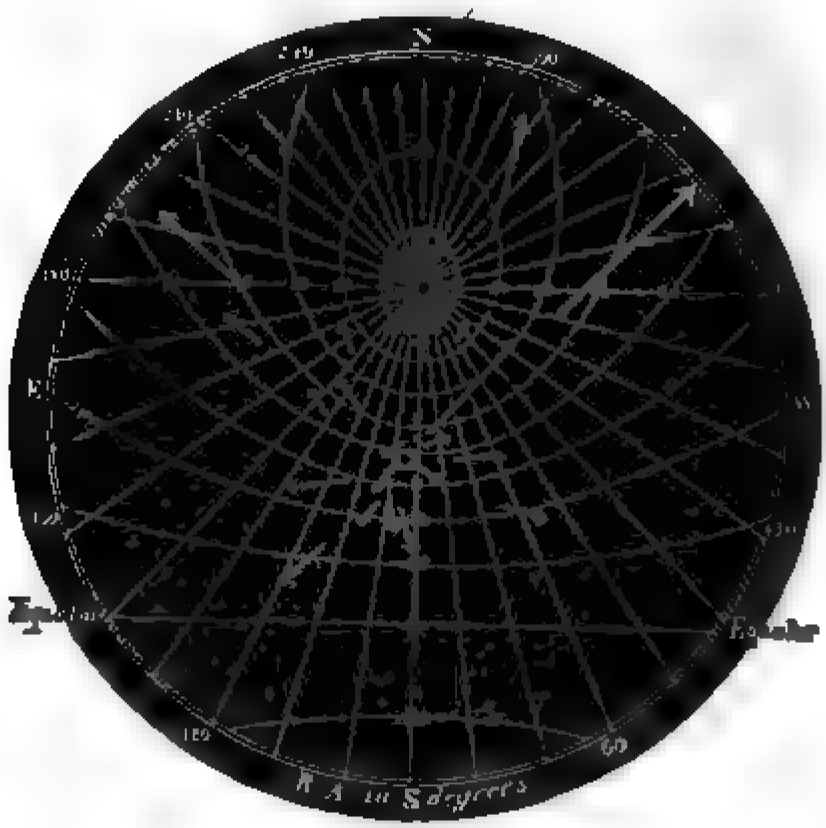
Of late years much attention has been devoted to the subject of luminous meteors. The British Association has a standing committee appointed to collect and record observations, and the systematised working of that committee and of the observers who co-operate with it is bearing valuable fruits. Amongst those who have exerted themselves to develope this branch of astronomy must be mentioned the names of Adams, Challis, Grant, Main, Glaisher, Lowe, Greg, A. S. Herschel, and Tupman, in England;

[h] *Nature*, vol. xi. p. 407, March 25, 1875; vol. xii. p. 85, June 3, 1875.

and among the chief astronomers abroad, who are either seeking or who have contributed to promote its progress, Twining and Newton, Loomis, Kirkwood, B. V. Marsh, Le Verrier, E. Quetelet, Buchner, Von Boguslawski, Galle, Heis, Neumayer, Schmidt, Weiss, Wolff, Schiaparelli, Denza, Secchi, Serpieri, and Tacchini, with other observers, especially in Italy, who pursue nightly watches for shooting stars, and regular reductions and discussions of meteor tracks with unremitting zeal.

The chief discovery that has been positively made is, that luminous meteors are much more regular in their movements than was

Fig. 271.



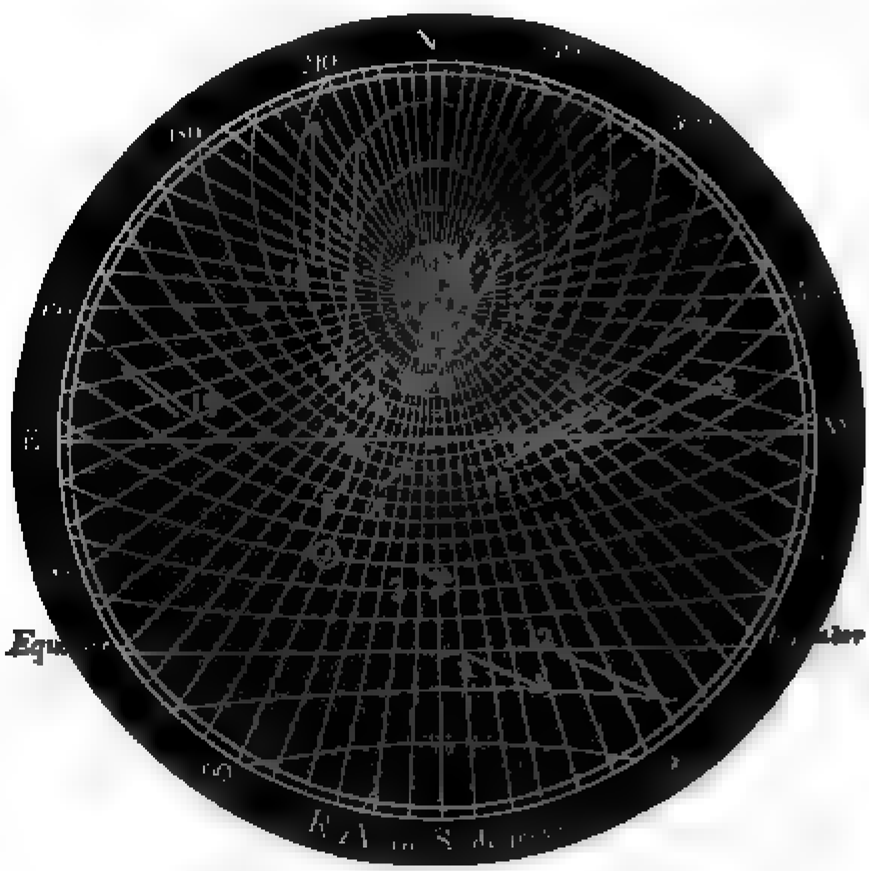
Radiant Point of Geminids (Dec. 12) on Nov. 28-Dec. 9, 1864.

formerly supposed. The known "radiant points" are no longer confined to the constellations Leo and Camelopardus, as they were when Sir J. Herschel wrote the passage which I have quoted on a previous page, but have been found to exist in many other quarters of the heavens. Up to the present time several hundreds of such points have been determined, and the number is growing as time progresses and observers multiply[1].

[1] For a recent summary of the progress made in this department of Science, see *British Association Report*, 1874, pp. 311–339; *Month. Not.*, vol. xxxv. p. 249, Feb. 1875.

Below is a list of the more important radiant points. It has been drawn up chiefly from Mr. Greg's comparative table of nearly 200 such positions[j], which is a valuable compilation of the catalogues of Heis, Schiaparelli and Zezioli, Schmidt, Tupman, and others. For the purposes of this list the *average* positions of some of the most important radiant centres are here collected, obtained directly from Mr. Greg's table and from a few additional sources, as no doubt in such averages greater accuracy is attained than by giving singly even the best individual determinations. The

Fig. 272.



RADIANT POINT OF ORIONIDS (OCT. 18–21) ON OCT. 20, 1865.

months or dates over which the showers extend are necessarily uncertain in many cases, and it is difficult to determine the precise duration of them, especially of those in operation for long periods. The "meridional position of the radiants by the stars" will be very useful to observers as a ready means of finding them, in the absence of a star chart or celestial globe. The notes affixed give Mr. Greg's remarks on the several showers, and some recent observations of the radiants by Mr. Denning are also included for comparison.

[j] *British Association Report*, 1874, p. 324.

LIST OF RADIANT POINTS

No.	Date of Shower.	Average position of Radiant Point. R. A. h. m.	Decl.	No. of Positions.	Meridional Position of Radiant by the Stars. (The letters N. E. S. W. denoting here the usual Astronomical directions n. f. s. p.)	No. in Greg's Catalogue, 1874.
1	January 1-3	15 32	+49	6	Bootis, 9° N.E. of β	6
2	February and March	12 8	+56	7	Ursa Major, 2° S. of δ ..	21, 46
3	February and March	11 56	+10	7	Virgo, 7° S.S.E. of β Leonis	28, 42
4	March and April	15 20	+35	4	Bootis, 7° S.E. of β	48
5	March and April	17 28	+14	5	Ophiuchus, 1° N. of α	50
6	April	17 20	+83	4	Ursa Minor, at ε	60
7	April	13 52	−5	2	Virgo, 11° N.E. of α	62
8	April 15-30	18 16	+35	5	Lyra, 5° S.W. of α and near ε	51
9	April, May, and June ..	16 0	+24	6	Corona, 1° E. of π and 8° E. of α	67
10	April and May	13 40	+54	4	Ursa Major, 4° N. of η ..	55
11	April 29—May 2	21 44	−2		Aquarius, 3° W. of α	61
12	June	20 24	+24	4	Vulpecula, 9° N. of α Delphini	74
13	June, July, and August ..	20 0	−1	12	Antinous, at θ	79
14	June, July, and August ..	22 40	+19	8	Pegasus, 6° N.W. of α ..	96-7
15	July and August	2 52	+56	9	Perseus, 3° N. of γ	108
16	July and August	22 20	−33	5	Piscis Australis, at β 6° W. of α (Fomalhaut)	94
17	July and August	20 40	+43	10	Cygnus, 1½° S. of α	81, 101
18	July and August	18 44	+60	6	Draco, 2° N.W. of o	78
19	July 21 and August ..	0 28	+33	6	Andromeda, midway between α and β	103
20	August and September .	23 28	+13	11	Pegasus, 7° E. of α	111
21	July 18—Aug 4	22 20	+41	4	Lacerta, 15° S. of ε Cephei ..	95
	August and September .	22 44	+58	4	Cepheus, 2° E. of δ	112
22	September and October ..	3 0	+30	5	Near Musca, 10° S. of β Persei	129
23	September and October .	5 24	+45	7	Auriga, between α and β ..	136
24	October and November ..	5 40	+16	6	Orion, 5° W. of ν	157
25	November 1-15	4 0	+18	6	Taurus, near Hyades, 4° W. of ε	156
26	October 17—November 3 ..	2 8	+21	3	Aries, 3° S.E. of α	154
27	November 12 17	9 56	+23	4	Leo, between ε and γ and 10° N. of α	171
28	November 27, 1872	1 40	+43	35	Andromeda, 3° W.N.W. of γ	172
29	November 23 and December	7 0	+31	8	Gemini, 5° W. of α, close to π	178
30	December and January .	9 4	+46	5	Ursa Major, 2° S.E. of κ ..	2

OF METEOR SHOWERS.

No.	Notes.
1	Circumpolar radiant; Quadrantids; max., 1835, '38, '63-4, and '72 (?). An annual shower.
2	A long-enduring shower, centre at 180° + 50° (Greg). At 184° + 54° March 1876 (Denning). There are several other radiants in Ursa Major for March and April.
3	Probably an elongated radiant advancing with the time from R.A. 174° to 190° and Dec. 20° to 0° (Greg).
4	At δ Boötis, 230° + 38° April 1876 (Denning).
5	Small meteors, with streaks. Max. April 13. At 273° + 25° April 13, 1864 (Herschel). At 267° + 25° April 20, 1872 (Greg).
6	Radiant near Polaris. Also well-marked radiants here for July—Aug., Sept.—Oct., and Dec. 15—Feb. 26.
7	Well observed 1874-76. Rad. region perhaps elongated, from 195° − 2° nearly to Libra for March—April (Denning). Max. April 18, 1841 (60^m in 2¼^h), precise at 198° − 8°.
8	The Lyrids. Max. April 19-20. Identical with Comet I, 1861. A fine though brief shower. Maxima in 1803, and 1863; annual, or rarely quite absent.
9	A long-enduring shower. At 241° + 24° April 1876 (Denning).
10	A long-enduring shower, probably 10 weeks and advancing with the time (Greg). At 207° + 48° April 1876 (Denning).
11	The Alpha-Aquariads. Average of 3 bright showers April 30—May 3, 1870, and April 29, 1871 (Tupman). A morning shower.
12	A well-marked radiant between Cygnus and Delphinus.
13	Average of 4 radiants at 294° − 7° (Schmidt), of 6, 292° − 11° (Tupman), and of 12, 300° − 1° (Greg). Some showers also in this period between μ and θ Aquarii.
14	The Pegasids. An important shower, with max. on about August 10 (Greg).
15	The Perseids. Max. August 9-11. Centre at 44° + 56° (1863, Schiaparelli); somewhat diffuse, elongated (or ? multiple) radiant region. Endures from July 20—Aug. 20 (?) (Tupman, 1869-71). Identical with Comet III, 1862 (Schiaparelli). Supposed period of shower 108 years; of comet 123 years.
16	A southern radiant. Neumayer; and well observed by A. S. Herschel July 28, 1865.
17	The Cygnids. Probably endures for 10 weeks, and is a well-marked shower for July—August with perhaps several radiants (Greg).
18	[There is a well-defined and long-enduring shower from this radiant also in April and May (Greg, No. 64); at 277° + 57° April—May, 1876 (Denning).]
19	A long-enduring and well-marked shower (Greg). Average of 3 radiants, 2° + 29° in 1869 (Denza).
20	Possibly a continuation of No. 14 (Pegasids) and closely connected with it (Greg). There is a marked shower with multiple or perhaps diffuse radiant region near α Pegasi between June and September.
21	(Schiaparelli and Zezioli). Lacertids. A notable shower, precise duration uncertain (Greg). Two showers, difficult to separate; and also contiguous to No. 14 above.
22	The Muscids. A well-marked shower, seen by several observers.
23	The Aurigids. An important and well-defined shower, centre near 82° + 50° (Greg.)
24	The Orionids. Max. Oct. 18-20, 1864-65 (Herschel). Average of 9 subradiants, Oct. 5-17, 1869, 90° + 11° (Tupman). A conspicuous shower Oct.—Nov. 10, 1874 (Denning).
25	The Taurids. A fine shower. Observed at Greenwich November 13, 1870, at 55° + 25°. A rich shower with well-defined double radiant 53° + 12°, and 56° + 20° (Tupman).
26	Schmidt and Tupman. A marked shower in October 1873 (Denning).
27	The Leonids. Max. November 13-14, 1866-67. Identical with Comet I, 1866. Period 33¼ yrs. The annual returns of this shower have quite ceased since Nov. 15, 1872.
28	The Andromedes. Identical with Biela's Comet. Duration probably Nov. 23—Dec. 4. Average of 35 central radiant positions Nov. 27, 1872, 25° + 43° (Herschel).
29	The Geminids. Max. Dec. 11-12. At 105° + 30° Dec. 12, 1863 (Greg & Herschel).
30	Centre about 135° + 48°. A distinct shower. Duration and max. date uncertain.

Figs. 271–2 (on pp. 812–3) represent the paths of certain meteors observed at the specified dates. Projected, after the manner of a surveyor's plan, to form a meteor chart, the fact that the meteors really are thrown off from some determinate centres becomes strikingly apparent. It is unfortunate for the sake of Science that the suddenness with which all these objects appear and the shortness of their duration usually take observers aback, and impair the certainty of their mental impressions, making it often difficult to obtain exactness. The plan of the projection used is that of a plane perspective view, in which the meteor-tracks observed can be represented by straight lines.

BOOK X.

SPECTROSCOPIC ASTRONOMY[a].

CHAPTER I.

INTRODUCTORY.

A Valuable Auxiliary to Astronomy.—Explanation of a Spectrum.—Historical account of the investigations respecting the Solar Spectrum.—Dark lines.—Kirchhoff's discoveries.—Varieties of Spectra.—Variations in the width of lines.

SPECTRUM analysis, or the determination of the constituent elements of a luminous body by the examination of its light after its passage through one or more prisms, has become during the last few years so valuable an auxiliary to the progress of Astronomy, that a treatise on that subject would now be imperfect which neglected to refer to it.

We owe to Newton the proof that sun-light, apparently so simple, is really complex, and compounded of many different colours. In a paper on Optics, presented to the Royal Society in 1672, he describes a series of experiments on the subject[b]. In one of these, he admitted a beam of light through a round hole into a darkened chamber; and fixing a prism close to the hole, placed a screen of white paper on the other side of the room to receive the rays. Had not the prism been there, the light would have

[a] I owe this Book to the kindness of Mr. E. W. Maunder, of the Spectroscopic Department of the Royal Observatory, Greenwich, and who is in a high degree competent to write on such a subject.

[b] *Phil. Trans.*, 1670–72, p. 3075.

followed a straight course and formed a round white spot on the screen. But instead, the direction of the beam was changed, and it formed on the screen an oblong rainbow-tinted band, equal in width to the diameter of the round white spot, but nearly five times as long. This Newton called the Solar Spectrum, and hence the image formed by the light of any luminous body, after it has passed through a prism, is said to be the spectrum of that body.

This rainbow-coloured strip consisted of a multitude of overlapping images of the aperture through which the light was admitted; each different coloured light forming its image on its own proper part of the spectrum.

Newton proved that the explanation of this phenomenon lay in the fact that all the colours of which white light is made up, are not equally refrangible; violet for instance being bent more out of its course by a prism than green is, and this again more than red. For the sake of convenience, and because it would be impossible to give a distinctive name to all the gradations of colour, seven only are generally recognised, though recently a necessity for more names seems to have been felt. These seven colours are violet, the most refrangible, and, in the order of their refrangibility, indigo, blue, green, yellow, orange and red. None of these can be again divided; so if green light for example be allowed to pass through another prism, it will still be green, and not show the slightest approach to violet or red.

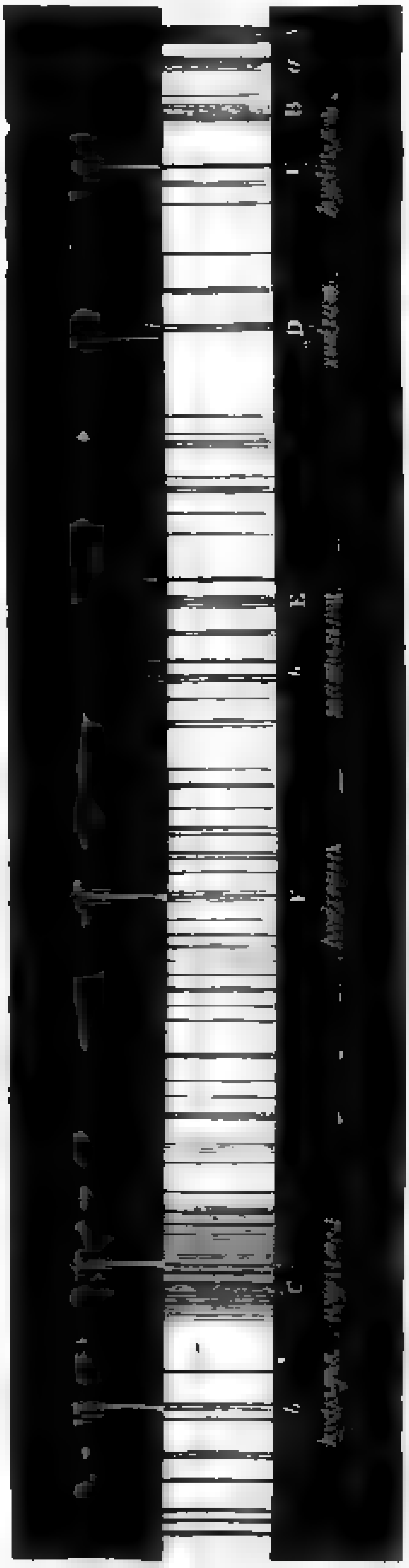
More than a century later Wollaston was anxious to find out if there were any distinctly marked limits to the different colours in the solar spectrum. It was evident that in Newton's experiment the colours were not obtained in a state of purity, for even if there were only seven different colours (and there are many more), the different images of the round hole must have over-lapped, as the entire spectrum was not five times as long as any one of them.

Wollaston therefore substituted a narrow slit for the round aperture, and at once perceived two gaps or dark lines; so that it became evident that the sun did not send us light of every degree of refrangibility [c].

[c] *Phil. Trans.*, vol. xcii. p. 378. 1802.

Wollaston went no further in his investigations, and no advance was made till, in 1814, Fraunhofer, a German optician, took up the same subject with wonderful success. Improving upon Wollaston, who viewed the spectrum directly with the eye, he used a small telescope, and discovered that instead of there being only two dark lines in the spectrum, its entire length was crowded with them. So numerous were they that he determined the positions of no less than 576[d]. The darkest of these, ever since called after him the Fraunhofer lines, he distinguished by the letters of the alphabet, and as they are continually referred to by these letters, it is important that their positions should be accurately borne in mind.

Fig. 273.



THE SOLAR SPECTRUM.

Seen with such a dispersive power as that which Fraunhofer used, A is a thick dark line at the extreme red end of the spectrum; B is also a broad line; between the two is a cluster of several lines, called *a*; C is dark and fine; all four of these are in the red. D is a very close pair of dark lines in the orange-yellow; E is the middle and darkest of a group in the yellowish-green; *b* a group of three dark lines where the green is more of an emerald tint; F seems to be about the boundary between green and blue; G is in a crowded cluster in the indigo; and H is a pair of bands near the limit of vision in the extreme violet.

[d] *Edin. Phil. Jour.*, vol. ix, p. 296. Oct. 1823.

Fraunhofer did not allow his researches to stop here. He proved that the same lines were seen whatever the prism employed, satisfied himself that they were invariable in their position, and determined their wave-lengths.

He further tried varying the source of light, and found that sun-light, whether taken directly or reflected from clouds or Moon or planets, gave the same spectrum.

He examined the light from the stars, and found that their spectra were also crossed by dark lines, but differently arranged in different stars, and in none exactly like those in the solar spectrum.

This precluded the idea that the cause of these lines lay in our own atmosphere, or in general Space, and established the important fact that their origin lay in the Sun and stars themselves.

Fraunhofer did not succeed in getting an artificial light to give a spectrum like that of the Sun, but in examining the light of a candle he remarked a most curious circumstance. It gave a perfectly continuous spectrum crossed by no dark lines, but in the orange, just where the two dark D lines are in the solar spectrum, he saw a pair of bright lines, proved afterwards by Swan to be due to the presence of sodium, the one perfectly coincident with one D line, and the other with the other.

In 1859 Dr. Kirchhoff, of Heidelberg, being in possession of a spectroscope of very considerable power, resolved to inquire whether this coincidence was perfect. "In order to test," he says, "in the most direct manner possible the frequently asserted fact of the coincidence of the sodium lines with the lines D, I obtained a tolerably bright solar spectrum, and brought a flame coloured by sodium vapour in front of the slit. I then saw the dark lines D change into bright ones. The flame of a Bunsen's lamp threw the bright sodium lines upon the solar spectrum with unexpected brilliancy. In order to find out the extent to which the intensity of the solar spectrum could be increased without impairing the distinctness of the sodium lines, I allowed the full sun-light to shine through the sodium flame, and to my astonishment saw that the dark lines D appeared with an extraordinary degree of clearness [e]."

Surprised to find that instead of supplying that lack of light of

[e] *Untersuchungen über das Sonnenspectrum*, p. 9. Berlin, 1862.

which the D lines were the evidence, the bright sodium flame only intensified it, Kirchhoff varied the experiment, and instead of sunlight employed the lime-light. "When this light was allowed to pass through a suitable flame coloured with sodium, dark lines were seen in the spectrum in the position of the sodium lines." Thus, instead of the brilliancy of the continuous spectrum of the lime-light being increased in the yellow by the interposition of the sodium flame, it was actually darkened, and as far as these two lines were concerned he had produced an artificial solar spectrum.

The interpretation of these two experiments supplies us with the principle upon which the application of spectroscopy to astronomy rests. It is thus worded by Prof. Roscoe: "Every substance which emits *at a given temperature* certain kinds of light must possess the power *at that same temperature* of absorbing the same kinds of light[f]." So that if light giving a perfectly complete and continuous spectrum be intercepted by a glowing vapour or gas giving a spectrum of bright lines, that light which corresponds to the bright lines will be stopped, for the gas will be opaque to it, and the remainder only will pass.

It does not follow from this that dark lines would always result in the spectrum. For as the glowing gas is emitting light of the very same quality as that which it absorbs, if it be at the same temperature as the source of the white light it will emit as much as it receives and thus give no sign of its presence. If it be hotter it will give off more than it receives, and hence cause *bright* lines; and only if it be the cooler will it emit less light than it absorbs and so occasion *dark* lines, and the greater the difference of temperature the darker the lines will be.

From these principles Kirchhoff concluded that the Sun is composed of a highly heated nucleus, to which the name of photosphere has been given, yielding a perfectly continuous spectrum, and surrounded by less highly heated vapours, sodium vapour being one, the spectra belonging to which give bright lines coincident in position with the Fraunhofer lines[g]. And it

[f] *Spectrum Analysis*, 2nd ed., p. 215.

[g] These bright lines themselves have been seen during total solar eclipses, when the overpowering light from the nucleus of the sun is hidden by the dark body of the moon. This "reversal of the spectrum" was first seen by Prof. Young in 1870; Capt. Herschel in 1871, and Stone in 1874 had a like success. The stratum giving this spectrum seems not to be more than 3″ of arc in depth.

necessarily followed that the lines in the spectra of stars must be interpreted in the same manner.

This great discovery had been anticipated. Ten years earlier M. Foucault had made almost exactly the same experiments with the sodium lines that Kirchhoff had done, but without drawing any conclusions from his observations [h]. Prof. W. H. Miller of Cambridge had established in 1850 by most careful measurements the perfect coincidence of the lines of sodium with the Fraunhofer lines D; Prof. Stokes had given the same explanation of the fact, afterwards given by Kirchhoff; and Sir William Thomson had in consequence taught regularly since 1852 that sodium was a constituent of the sun's atmosphere [i]. The celebrated Ångström of Upsala in 1853 had independently arrived at very similar conclusions, and almost at the time of Kirchhoff's discoveries Prof. Balfour Stewart was engaged in demonstrating this "Theory of Exchanges." Nevertheless it was not until Kirchhoff's labours that spectrum analysis became actively enlisted in the cause of Astronomy, although the principle he enunciated was already known to certain individual philosophers, and even to a small extent applied.

In the interval between Fraunhofer's discovery of the dark lines in the solar spectrum and Kirchhoff's explanation of them, much progress had been made in spectrum analysis as far as it applied to terrestrial substances, and certain leading principles laid down, the which, as they bear equally on astronomical work, must here be briefly referred to.

By the inquiries of Fox Talbot, Wheatstone, Foucault, Brewster and others, three kinds of spectra had been defined.

(1.) The spectrum of an incandescent solid or liquid, which is always perfectly continuous, shewing neither dark lines nor bright [k].
(2.) The spectrum of a glowing gas, which consists of bright lines or bands separated by dark spaces. These lines are characteristic of the element that causes them, and so from the position of the bright lines in a spectrum it is possible to tell their origin. The electric spark gives a spectrum which consists of the bright lines belonging to the vapours of the electrodes, and to the

[h] *L'Institut*, Feb. 7, 1849, p. 45.

[i] President's Address, British Association. 1871.

[k] The rare earth Erbia, when incandescent, shews bright lines.

gases through which the discharge takes place. (3.) A spectrum crossed by dark lines. This occurs when an incandescent solid is viewed through absorbent vapours. From Kirchhoff's principle it follows that if the absorbing vapour itself gives a spectrum of bright lines, the dark lines it causes will exactly correspond to them, and hence be as sure an indication of its presence as the bright lines would be.

The researches of Huggins, Lockyer, and Frankland have shewn us how to interpret variations in the width of a line; an increase of pressure causing the lines to widen equally in both directions[1]. A twist, or widening in one direction only, or an entire displacement, is due to another cause, and it enables us to determine the rate at which a luminous body is approaching us or receding from us. The impression of colour made on the eye depends on the interval between the waves of light as they enter it. Thus the shortest waves produce the sensation of violet, and the longest of red. So if a stream of glowing hydrogen is rapidly approaching the observer, a greater number of waves of light from it will enter his eye in a second than if the source of light were at rest, and therefore the intervals between the waves, in other words the wave-lengths, would seem to be diminished. So that if he were examining, say the line corresponding to F, it would seem to be more of a violet hue than before. It will therefore be seen displaced in the spectrum in that direction, as compared with the same line given by the hydrogen in a vacuum tube, or with other lines in the sun, the elements occasioning which are at rest. In like manner, if the source of light be receding, the waves of light seem lengthened, and any particular line will seem to be displaced towards the red end of the spectrum.

Although so short a time has elapsed since the foundation of spectroscopic astronomy, yet so many observers have devoted themselves to it, that it already boasts an extensive and rapidly increasing literature, while it has solved several interesting and important problems hitherto regarded as quite beyond our reach.

Its leading results and the methods by which they have been obtained may now be briefly passed in review.

[1] *Phil. Trans.*, vol. clviii. p. 547. 1868.

CHAPTER II.

SPECTROSCOPY AS APPLIED TO THE HEAVENLY BODIES.

The Solar Spectrum described.—Atmospheric lines.—Janssen's experiments.—Spectrum observations of Sun Spots.—Of Faculæ.—Of Prominences.—Labours of Lockyer and Janssen.—Researches of Respighi and Secchi on Solar activity.—The Solar Corona.—The Zodiacal Light.—Spectra of Planets.—Of Comets.—Of Stars.—Secchi's Classification of the Spectra of Stars.—Huggins's investigation on the movements of Stars in the line of Sight.—Spectra of Nebulæ.—Of Meteors.

The Sun.—Kirchhoff having explained the presence of two of the solar lines, endeavoured to account for others. Instead of the simple spectrum of sodium, however, he took the most complicated that he had at hand. There are no less than 450 lines in the spectrum of iron, and he resolved to ascertain if any of these were coincident with any of the solar lines. Placing a small right-angled prism before the upper half of the slit so as to reflect the light from an electric spark passing between electrodes of iron, while sunlight was admitted directly through the lower half, he obtained the two spectra one above the other, rendering comparison easy. To his surprise and delight, every bright line in the spectrum of iron had its counterpart in a dark line in the solar spectrum, and not only so, but each strong line was represented by a strong line, each faint line by a faint line [a].

This work of comparison was zealously continued by Kirchhoff and Bunsen, and by Ångström of Upsala, and the spectra of some 13 or 14 elements were found to give bright lines corresponding with solar lines, while several others gave not a single coincidence.

Of this latter class are gold, silver, tin, lead, antimony, arsenic, mercury, cadmium, strontium, and lithium. The following table, drawn up by Ångström, shews the elements that have been

[a] *Untersuchungen über das Sonnenspectrum*, p. 12.

recognised in the solar atmosphere, and the number of coincidences established :—

Hydrogen	4	Manganese	57
Sodium	9	Chromium	18
Barium	11	Cobalt	19
Calcium	75	Nickel	33
Magnesium	4 + (3)?	Zinc	2 (?)
Aluminium	2?	Copper	7
Iron	450	Titanium	118

The number of coincidences in the case of titanium has been lately very largely increased by Ångström's coadjutor, Thalén.

Both Kirchhoff and Ångström have very carefully mapped the solar spectrum. Kirchhoff's map shews it as actually seen with his spectroscope, and is so accurate and complete, that lines are constantly referred to by their numbers on his scale, just as a star might be particularized by its number in the British Association Catalogue. Ångström's map is of the normal spectrum, i.e. the lines are mapped according to their wave-lengths.

The absence of dark lines corresponding to the bright lines of any element is no proof that it does not exist in the sun. For it may be at such a temperature as to emit about as much light as it absorbs, or its vapour may be so heavy as not to rise above the level whence the white light of the sun proceeds, or it may even be in such a condition as to give a continuous spectrum itself; and in none of these cases would it give evidence of its presence.

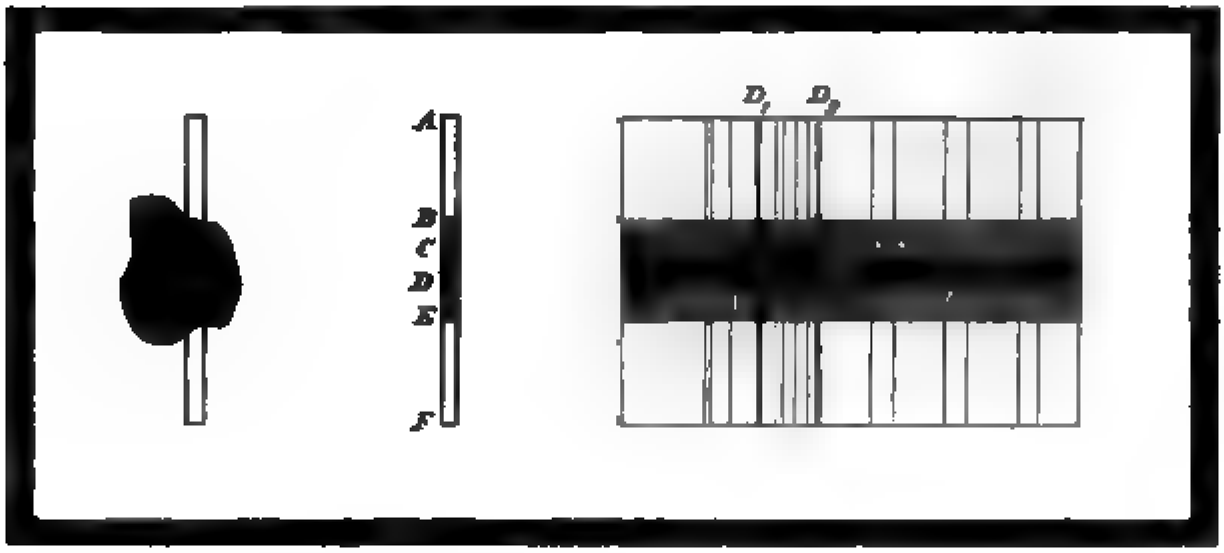
But although we are not able to recognise in the sun all the elements with which we are acquainted, nor even to identify the origin of all the Fraunhofer lines, yet, as Ångström remarks, "the number already mapped suffices to shew, that to account for the origin of almost all the more prominent rays in the solar spectrum, we must assume that the substances constituting the chief mass of the sun are without doubt the same substances as exist on our planet [b]."

ATMOSPHERIC LINES.—Not all the dark lines seen in the sun's spectrum can be thus explained, for some are undoubtedly due to the influence of our own atmosphere. Brewster, long before Kirchhoff's discovery, had noticed that certain lines which were dark and strong when the sun was on the horizon grew faint or disappeared altogether

[b] *Recherches sur le Spectre Solaire*, par A. J. Ångström, p. 35.

when it was high in the heavens, and with Dr. Gladstone in 1860 he carefully mapped the solar spectrum with special reference to these atmospheric bands[c]. Ångström and Secchi have also paid great attention to the same subject, but no one more than Janssen, who remained in 1864 for a week on the summit of the Faulhorn in Switzerland, at a height of 9000 feet above the sea, and there found the lines due to atmospheric influence much fainter than in the plains. He also from thence examined the spectrum of the light from a large fire of pine wood, which he caused to be made at Geneva, 13 miles from his place of observation. When viewed near at hand the fire presented a continuous spectrum with no lines, but at the full distance there appeared several of the dark lines which are seen at sunset.

Fig. 274.



Sun-Spot and part of its Spectrum near line *D*.

Again at Paris in 1866 Janssen conducted an even more instructive experiment, which proved aqueous vapour to be the source of many of these *telluric* bands as they are called. The light from 16 gas-burners was caused to pass through a thickness of 118 feet of steam, preserved from condensation by special contrivances. The spectrum of this light in the air was entirely free from absorption lines, but, through the steam, groups of lines coincident with some of those in the spectrum of the setting Sun were at once observed[d].

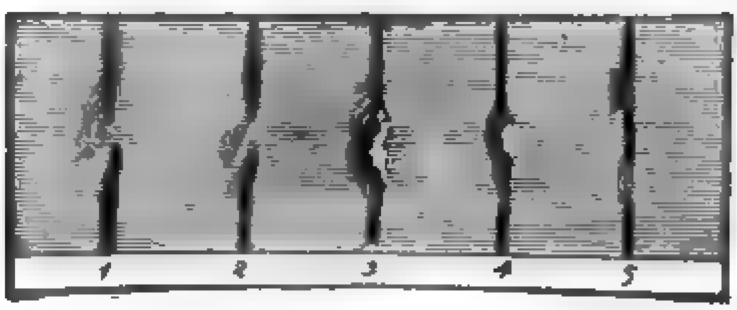
Sun-spots.—For the examination of details of the surface a fairly

[c] *Phil. Trans.*, vol. cl. p. 149. 1860.
[d] *Comptes Rendus*, vol. lx. p. 213, Jan. 30, 1865, and vol. lxiii. p. 289, Aug. 13, 1866.

large image of the sun is needed, and this is generally obtained by using a telescope of long focus. The general appearance presented by the spectra of the different parts of a spot is shewn in fig. 274. The left-hand figure shews the position of the slit on the spot. The centre one shews the portion of the spot covered by the slit, which is what an observer looking directly at the sun through the slit would see. The portions AB, EF, at either end of the slit, belong to the clear surface of the sun, the middle part CD to the umbra of the spot, and the parts between BC and DE to the penumbra. Corresponding to these five parts we have five narrow spectra, the centre one that of the umbra, on each side of it a spectrum of the penumbra, and outside these an ordinary solar spectrum.

In spite of their darkness as compared with the general surface

Fig. 275.



CONTORTIONS OF *F* LINE ON DISC OF SUN.

Nos. 1 and 2, rapid down-rush and increasing temperature: 3 and 4, up-rush of bright hydrogen and down-rush of cool hydrogen; 5, local down-rushes associated with hydrogen at rest.

spots give a perfect solar spectrum, only much fainter than that given by the rest of the disc, shewing an increase of *general* absorption. But this is not all. Individual lines are frequently seen to be much widened, and very many of those lines that usually appear fine and faint become much broader and darker. The lines due to sodium, iron, and magnesium are generally affected, but those of titanium, barium, and calcium especially so. Secchi, who has devoted much attention to the examination of sun-spots, has also noticed the appearance of fresh absorption lines in their spectra, which he believes to be due to aqueous vapour; for he found that the same bands appeared in the spectrum of the clear part of the sun's disc when it was viewed through cloud or fog, and that they were then much darker over the spot itself*.

* *Comptes Rendus*, vol. lxviii. p. 358. Feb. 15, 1869.

Another remarkable feature is that it is by no means uncommon to find *bright* lines in the spectrum of a spot; while Lockyer has seen a line both dark and bright at the same time, the dark part being bent to the red, the bright to the violet; thus shewing that there was a downrush of cooler gas from the surface, and a corresponding ejection of the more highly heated gases of the interior. The same observer has frequently noticed the most singular and fantastic twistings and bendings in particular lines over a sun-spot, especially F, due to hydrogen, shewing movements and variations of pressure of the most complicated character[f].

The spectra of the different parts of a spot are by no means identical. In 1869 Secchi examined a fine spot that was crossed by a brilliant bridge. The bridge shewed an ordinary solar spectrum, but with the hydrogen lines bright instead of dark; these bright lines penetrated some distance into the spectrum of the umbra, while in that of the penumbra no lines could be perceived either dark or bright. The umbra also shewed the absorption bands which Secchi has ascribed to aqueous vapour, but in addition some bright double lines in the green; an observation that seems at present to stand in need of further confirmation.

Prof. Young in examining a spot spectrum on one occasion noticed between C and D some shaded bands, terminated abruptly at the end nearer the red by a hard dark line, but fading out gradually towards the violet at a distance of three or four divisions of Kirchhoff's scale. These, he suggests, may indicate the formation of compound bodies, in consequence of a lowering of temperature; the solar heat usually causing the dissociation of the elements composing them[g].

The evidence of the spectroscope on the constitution of spots shews us, then, that the general absorption is much increased, and that many vapours and gases are at a much greater pressure there than at the general surface of the sun, hydrogen and, less frequently, other vapours rushing down with great velocity into its depths, an effect which is sometimes compensated for by the up-whirling of the glowing gases of the strata below.

Faculæ.—These give, according to Lockyer, an ordinary solar spectrum but with *diminished* absorption, both general and par-

[f] *Solar Physics*, p. 233.
[g] *Nature*, vol. vii. p. 109. Dec. 12, 1872.

ticular; the whole spectrum being brighter than that of the general surface, and individual lines being often missing. This would seem to shew that they are elevations above the ordinary surface, and hence are seen through a less depth of atmosphere [h].

PROMINENCES.—Total eclipses of the Sun some few years before Kirchhoff's discovery, had revealed to astronomers the fact that the Sun was surrounded by appendages of the strangest character. First, by a thin rose-coloured envelope from which sprang fantastic looking prominences of the same colour; then by a halo of silver-white light known as the corona; and beyond this by some fainter radiations of it extending in some cases more than a degree from the sun's surface.

The origin and nature of these appearances were involved in mystery, and, until the spectroscope was called into action, there seemed no likelihood of explaining them. In the eclipse of 1868, at the suggestion of Col. Tennant, the spectroscope was added to the weapons of research, and it at once revealed to M. Janssen that the prominences give a spectrum of bright lines, and therefore consist of glowing gas [i]. Struck with the exceeding brilliancy of two of the prominences he resolved to endeavour to see the lines when the sun was no longer eclipsed, and putting his project into execution on the morrow met with complete success.

The principle by which it was effected is briefly this. The hindrance to seeing the prominence lines at all times is in the overpowering light which our atmosphere reflects from the sun. But the spectrum of this light being simply that of reflected sun-light can be weakened to any required degree by increasing the dispersive power and so lengthening out the spectrum; while that of the prominences, consisting mainly of three bright lines, suffers very little diminution of intensity in each line by the increase of the dispersion; its principal effect being simply to increase the distance between them.

Mr. Lockyer had suggested, almost two years earlier, the application of the spectroscope for seeing the prominences, but lack of instrumental power prevented him from succeeding, until shortly after Janssen's discovery [k].

[h] *Solar Physics*, pp. 319 and 404.

[i] *Annuaire du Bureau des Longitudes*, 1869, p. 584.

[k] *Solar Physics*, p. 570; but see *Month. Not.*, vol. xxviii. p. 88, Feb. 1868.

Huggins and Stone had also endeavoured in the same manner to see the prominence-spectrum, but failed, from the same cause that so long hindered Lockyer, namely insufficient dispersive power.

The ordinary prominence-spectrum consists of the four lines of hydrogen, of which the two violet lines are usually too faint to be usefully dealt with, and a fifth line, in the yellow, close by the D lines and known[1] as D_3.

This yellow line is not found in the spectrum of any known element, nor is any corresponding dark line usually seen in the solar spectrum. Secchi indeed states that he has seen it bright on the sun's disc.

Fig. 276.

C

Spectrum of the Sun near line *C* with the Slit Radial.

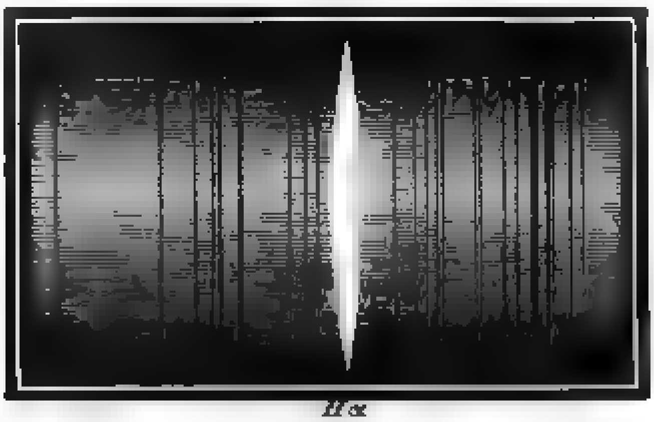
The same lines, but shorter than in the prominences, are found all round the Sun and are given by the rose-coloured envelope noticed in eclipses, from which the prominences rise. This stratum has been named the chromosphere.

The lines of other elements frequently appear in the spectrum of the chromosphere or prominences, but they do not attain nearly the same height that the hydrogen lines do. Sodium, magnesium, and

[1] The application of a letter to this bright line is not in accordance with the general rule by which the letters given by Fraunhofer are used to distinguish only dark absorption lines. Thus the bright lines of hydrogen are known as H α, H β, H γ, and H δ, but the dark lines corresponding to them as C, F, 2796 K, and *h*.

iron are often to be seen, and on one occasion Lockyer saw *hundreds* of the Fraunhofer lines reversed, that is, bright on a dark background, at the foot of a prominence [m]. Occasionally however these heavier metals are flung out to much greater heights, and the

Fig. 277.



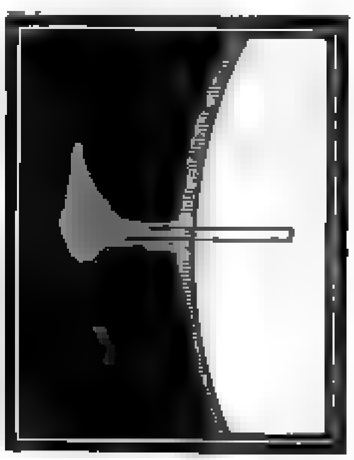
$H\alpha$

SPECTRUM OF THE SUN WITH SLIT TANGENTIAL, SHOWING LINE *C* REVERSED ON THE CHROMOSPHERE.

same observer once saw a cloud of magnesium vapour floating over a prominence.

The bright lines of hydrogen generally taper towards a point, the greater their distance from the limb. This is particularly the case with the H β line, the "arrow-headed" appearance of which

Fig 278.



SLIT PLACED RADIALLY TO VIEW A PROMINENCE.

Fig. 279.

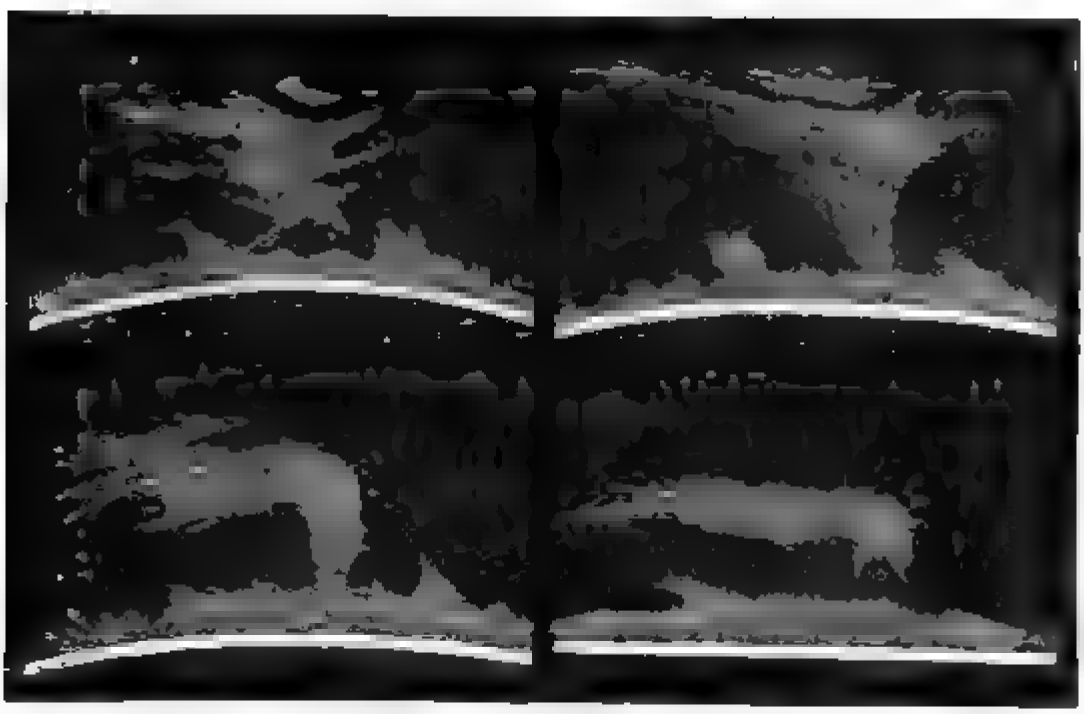
SLIT PLACED TANGENTIALLY TO VIEW A PROMINENCE.

close to the edge of the disc has often been remarked by Lockyer, Young and others; and plainly indicates that the pressure rapidly diminishes from the limb outwards. The metallic lines also appear thinner when seen bright in the chromosphere than when

[m] *Solar Physics*, p. 521.

seen dark on the sun. In order to see the spectrum of the chromosphere, the spectroscope may be placed in one of two positions, either with the slit perpendicular to the image of the sun's limb, or else tangential to it. In the former case the spectrum obtained will shew above the solar spectrum a number of bright lines of varying lengths. In the latter case, the faint solar spectrum reflected from the air occupies the whole breadth of the field, but is crossed by three principal bright curved lines in place of the dark ones C, D_3 and F. The spectrum near C as seen with a radial slit is shewn in fig. 276, and with a tangential slit in fig. 277.

Fig. 280.



Changes in Prominences noticed by Young.

Huggins soon shewed that it was possible by using a greater dispersion to open the slit wide enough to see the prominence itself. The atmospheric spectrum then becomes very impure, so that the Fraunhofer lines disappear. The image of the sun is carefully kept close to, but outside the slit, or else its great brilliancy would to some extent dazzle the eye and prevent the observer seeing the details of the prominences under inspection.

Lockyer, Zöllner and others, at once made use of this improvement, and the very first observations of Zöllner induced him to divide them into two classes, clouds and jets. Respighi however considers that all prominences are eruptive in their origin.

These jets and clouds of glowing gas are in a constant state of change, usually pretty gradual, but occasionally very rapid. Zöllner noticed a *flickering* movement on one occasion, resembling the tongue-like motion of a flame. This observation is rendered very probable from the similar one of Dawes in the eclipse of 1851[n]. Storms of the most violent nature have also been occasionally witnessed. Prof. Young on the 7th of September 1871 saw a prominence 100,000 miles long, by 54,000 high, after the most rapid and wonderful changes, vanish altogether in about two hours. In ten minutes parts of the prominence had risen fully 100,000 miles, the greater portion of it having been "literally blown to shreds[o]." The accompanying sketches of the changes in another prominence noticed by the same observer, are interesting from the indications which they afford of violent side winds as well as of eruptive force.

Fig. 281.

BENDING OF THE LINE Hβ IN THE SPECTRUM OF A PROMINENCE.

Evidence of motion is supplied also by the bending of the prominence lines; indeed their displacement is often much more marked than that of the lines of spots. According to Lockyer the motion, as thus evidenced, of the gas streams is frequently 40 miles per second for vertical movements; and in cyclonic or horizontal movements as great as 120[p].

At the present time of minimum solar activity (1876) these great storms have quite ceased, and the solar atmosphere is usually in a state of complete calm. Fine jets will rise to a height of, in some cases, 2 minutes of arc without any bending, and then gently and gradually spread out equally in both directions, symptoms of the violent winds which at the time of maximum activity forced prominences into long horizontal streams, having quite disappeared[q].

Respighi, adopting Huggins's improvement, has commenced an entirely new department of solar observation, closely corresponding in its nature to that of Schwabe and Carrington with regard to

[n] See p. 187, *ante*.
[o] *Boston Journal of Chemistry*, vol. vi. p. 49. Nov. 1871.
[p] *Solar Physics*, p. 493.
[q] *Comptes Rendus*, vol. lxxxii. p. 717. March 27, 1876.

sun spots; namely the daily measurement and delineation of all the prominences visible round the sun's disc.

Respighi carried on this work from Oct. 26, 1869 to April 30, 1872, with an interruption of about six months in 1871. This gap is fortunately covered by the similar observations of Secchi, who has continued them down to the present time. Both these observers arrange their sketches of the prominences on any day in a straight line, which is marked off into divisions corresponding to degrees of the sun's circumference. A glance at a series of these maps shews in what parts the prominences abound, and where they are least frequent.

These observations therefore commence shortly before the last spot-maximum and embrace the whole period of decline to the present strongly marked minimum.

From this series Secchi remarks the following facts:—(1.) The time of maximum of activity is the same for spots, faculæ and prominences. (2.) The prominences and spots decrease in number and size together, and the great metallic eruptions have passed away with the great spots; so that the prominences now (1876) consist almost entirely of hydrogen. (3.) The prominences are connected rather with the faculæ than with the spots; for though at present all occupy much the same zones, yet, when the prominences were there, the faculæ abounded in the polar regions where spots are never seen[1].

CORONA AND ZODIACAL LIGHT.—Since Lockyer and Janssen shewed how the prominences might be observed in full sunshine, the chief interest of total solar eclipses has centred in the corona, and in spite of many difficulties good results have been achieved. Indeed no revelation due to the spectroscope has proved more strange and unexpected than its testimony as to this mysterious halo.

The importance and interest attaching to so vast an appendage of the Sun, extending as it does in some of its fainter filaments nearly 2,000,000 miles from the sun's edge, would of itself be great if the fact of its having these dimensions stood entirely alone. But we now find it intimately connected with two other phenomena for which explanations had long been wanting.

[1] *Comptes Rendus*, vol. lxxxi. p. 605. Oct. 11, 1875.

The spectrum of the Corona consists of two parts: a continuous spectrum, crossed in some instances at least by the dark Fraunhofer lines, and therefore giving evidence of being reflected sunlight; and a spectrum of bright-lines [s].

The exterior portion yields only one green line, 1474 on Kirchhoff's scale, but close to the sun we find a stratum consisting of hydrogen gas at a temperature much lower than that which is found in the prominences. Beside the hydrogen lines and 1474 K, Prof. Young noticed two other lines, which with 1474 K, Prof. Winlock observed in the spectrum of the Aurora. Now the Aurora is supposed to be due to discharges of electricity in the upper and rarer regions of our own atmosphere. That similar discharges should take place in the corresponding regions of the solar atmosphere can excite no surprise; indeed the violent eruptions often witnessed in the prominences must naturally give rise to them. The spectrum of reflected sunlight given by the Corona, or at all events by the outer portion of it, seems best explained by the hypothesis that the neighbourhood of the Sun is filled by clouds of meteorites, a theory rendered probable by several considerations. First, the incalculable number of meteor-streams that must exist in the solar system, seeing that we encounter at least one hundred in the course of a year. If they even existed by millions the chance of but one such encounter would be small indeed. Next, the fact that the perihelia of comets (and the only meteor-systems whose orbits have been determined travel on the same orbits with well-known comets) are much more numerous as we approach the Sun. And lastly, the researches of Le Verrier into the motions of Mercury, which prove that the perturbations of that planet would be explained if such an aggregation of matter existed in its vicinity.

The coronal line 1474 K was at first supposed to be coincident with a line of iron, but Dr. Vogel finds a slight difference in position [t]. It may therefore be taken to reveal the existence of a gas, as yet unknown to us, much lighter than hydrogen, and very widely diffused throughout the coronal region in a state of great tenuity.

The spectrum of the Zodiacal Light has been differently reported

[s] *Proc. Roy. Soc.*, vol. xx. p. 139, Feb. 1, 1872; *Mem.* R.A.S., vol. xlii. p. 46. 1875.

[t] *Beobachtungen angestellt auf der Sternwarte zu Bothkamp*, Part i. pp. 36-7. 1872.

on by different observers. Ångström found a single line coincident in position with the brightest of the Aurora[w], but Arcimis, from observations made at Cadiz[x], pronounces it to be the same as that of the Corona, namely, a continuous spectrum and the bright line 1474 K.

It would perhaps be premature, at present, to attempt to frame a theory completely to explain the strange connection thus hinted at between these three phenomena; but as the Zodiacal Light itself has long been held by most astronomers of eminence to be caused by the reflection of sunlight from great numbers of meteorites arranged in a ring around the Sun, it may fairly be considered as an additional indication of the meteoric character of the Corona.

Planets.—The Spectroscope can tell us comparatively little about these bodies, for as they shine not by their own, but by reflected light, their spectra are, for the most part, the reflection of that of the Sun. So that all we can learn is whether this has been modified by any absorptive property of their several atmospheres.

The Moon, however, shews no sign of any modification of this kind; this evidence, as far as it goes, therefore negatives the theory of a lunar atmosphere. But an observation of Huggins's is much more decisive. He watched the occultation of a star by the dark limb of the Moon. Now if the star had suffered any appreciable refraction by a lunar atmosphere, the violet end of the spectrum would have been visible a little longer than the red, as it would have been more refracted. But nothing of the kind was noticed, the entire spectrum vanishing at once[y].

The three smaller planets, Mercury, Venus, and Mars, give the usual solar spectrum, but in addition, there have been noticed bands agreeing in position with some of the telluric bands, particularly in the red, and, in the case of Mars, near D. It is of course by no means easy to make sure that these are not occasioned by the action of our own atmosphere; but the careful observations of Dr. Vogel and others have rendered it very probable that they are really due to the atmosphere of the planet under inspection. In the case of Mars, Huggins saw these lines when the Moon, which was considerably lower in the heavens, was free from lines[z].

[w] *Recherches sur le Spectre Solaire,* p. 41.

[x] *Month. Not.,* vol. xxxvi. p. 48. Nov. 1875.

[y] *Month. Not.,* vol. xxv. p. 60. Jan. 1865.

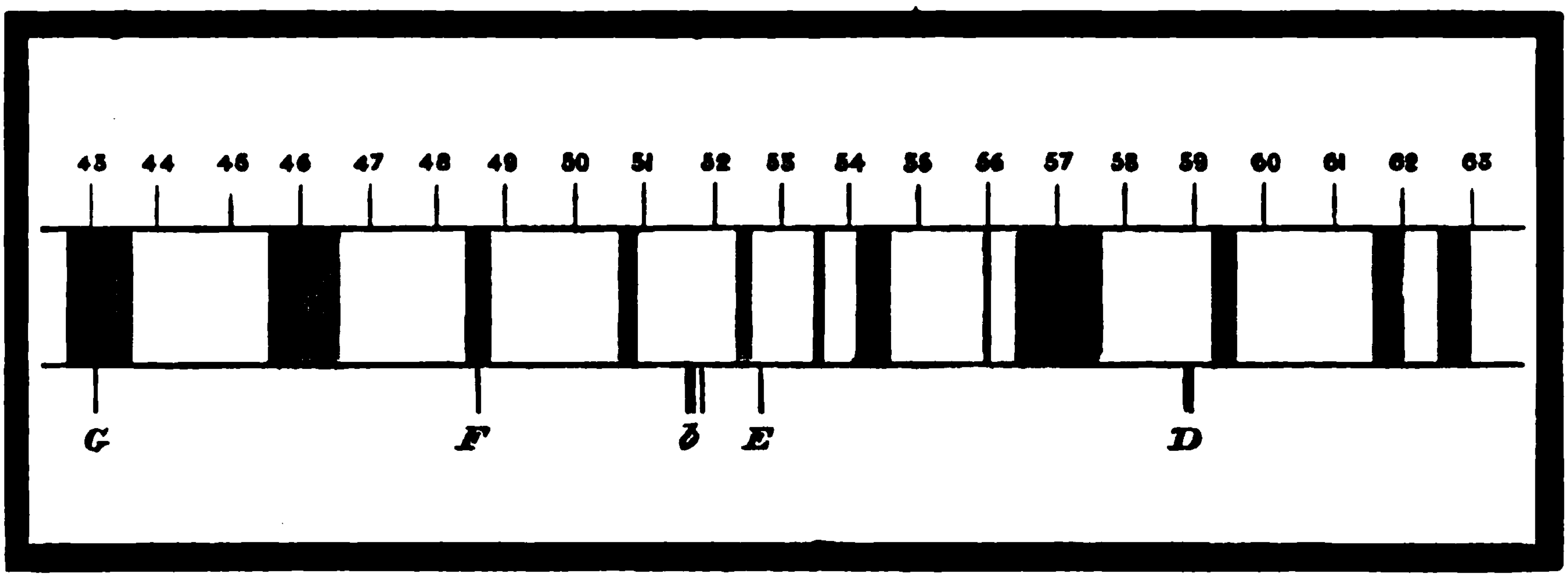
[z] *Month. Not.,* vol. xxvii. p. 178. March 1867.

Jupiter and Saturn, like the smaller planets, shew traces of absorption by aqueous vapour, in addition to the reflected solar spectrum.

But in addition there is a band in both spectra that cannot be assigned to either of these origins, and hence we may conclude that the atmospheres of these planets contain some vapour or gas unknown to us[a]. Dr. Vogel suspects the presence of the same band in the spectra of the II and IV satellites of Jupiter.

Huggins finds that the bands due to aqueous vapour are less distinctly marked in the spectra of the ansæ of the rings of Saturn than in the spectrum of the ball, thus shewing that the absorptive power of the atmosphere surrounding the ball is greater than that of the atmosphere surrounding the rings[b].

Fig. 282.



SPECTRUM OF URANUS.

But of all the planets, the two outer, Uranus and Neptune, especially the former, give the most remarkable spectra. The faintness of their light does not permit the Fraunhofer lines to be seen, nor are the telluric bands noticeable. In the case of Uranus six strong bands however are noticed by Huggins; and Vogel, who confirms the observations, adds a few fainter ones[c]. One of the darkest is coincident with the blue-green line of hydrogen, but none of the others have been certainly identified. Another strong band is coincident with the one remarked in the spectra of Jupiter and Saturn.

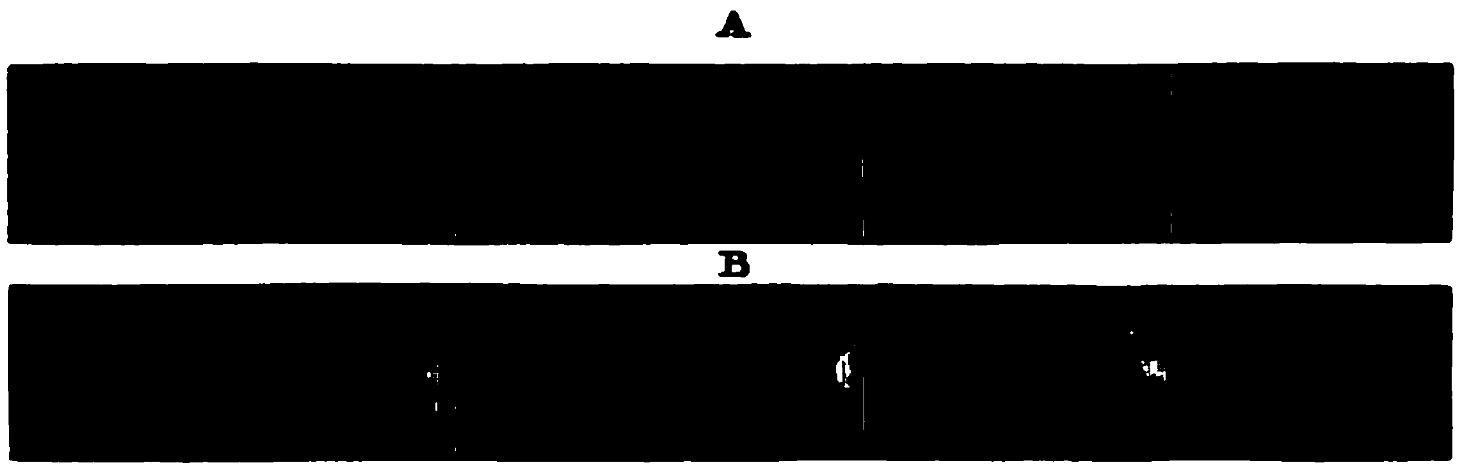
[a] *Proc. Roy. Soc.*, vol. xviii. p. 248. March 3, 1870.
[b] *Brit. Assoc. Rep.*, 1868, p. 143.
[c] *Proc. Roy. Soc.*, vol. xix. p. 489.

The light of Neptune is almost too faint for such a difficult observation, but Dr. Vogel finds three bands in its spectrum agreeing, within the limits of observation, with three of the darkest in that of Uranus[d].

Comets.—Unfortunately since the application of spectrum analysis to astronomy, the comets that have visited our system, with the exception of Coggia's in 1874, have been very small and insignificant, while the position of that one made observation difficult. Still the examination of those that have been available has given noteworthy results.

The first comet the spectrum of which was observed was comet i. 1864 by Donati, who found it to yield only three bright lines, shewing the presence of a glowing gas. Huggins and Secchi in 1866 found Tempel's comet give likewise three bright lines and

Fig. 283.



Spectra of Olefiant Gas and Winnecke's Comet. 1868.
A, Gas: B, Comet.

a continuous spectrum in addition. No dark lines were perceived in the latter, the light being probably too faint to enable them to be seen. But in the continuous spectrum yielded by Coggia's comet of 1874, as observed by Christie at Greenwich, some dark lines were seen, and therefore it is reasonable to conclude that the continuous spectrum given by comets is simply due to reflected sunlight[e].

Huggins and Secchi in examining the head of Winnecke's comet in 1868 saw three bands, besides the continuous spectrum, and on comparing them with olefiant gas, found that they were exactly coincident with the three principal bands of the carbon compounds[f]. The observations of Coggia's comet yielded the same

[d] Vogel, *Untersuchungen ueber die Spectra der Planeten.* Leipzig, 1874.

[e] *Month. Not.*, vol. xxxiv. p. 491. 1874.

[f] *Phil Trans.*, vol. clviii. p. 555. 1868.

result. In all cases the tail of the comet only gave the spectrum of reflected sunlight.

We may therefore conclude that comets, besides reflecting the Sun's light to us, shine by light of their own, that light consisting probably of burning carbon or some of its compounds.

STARS.—Shortly after Kirchhoff had commenced his work of comparing the spectra of various elements with that of the Sun, Huggins and Miller applied the same method to ascertain the nature of the elements contained in the stars. The conditions of work were however widely different in their enterprise from what they had been in Kirchhoff's. It was no longer the blaze of sunlight, but the tiny glimmer of a star that had to be spread out into a long spectrum. Indeed it was necessary still further to weaken the feeble light by a cylindrical lens, in order to give the spectrum a sensible width; for otherwise a star spectrum would be merely a coloured line, stars having no appreciable diameter.

The extreme difficulty and delicacy of this work can hardly be appreciated by any one who has not actually tried it, and it reveals a patient laboriousness on the part of these observers not to be surpassed. The results of their observations in the case of Aldebaran and Betelgeuse are thus given by Huggins:—

ELEMENTS COMPARED WITH ALDEBARAN.

Coincident.

1. Hydrogen with lines C and F.
2. Sodium with double line D.
3. Magnesium with triple line *b*.
4. Calcium with four lines.
5. Iron with four lines and E.
6. Bismuth with four lines.
7. Tellurium with four lines.
8. Antimony with three lines.
9. Mercury with four lines.

Not coincident.

Nitrogen	compared	with	3	lines.
Cobalt	,,	,,	2	,,
Tin	,,	,,	5	,,
Lead	,,	,,	2	,,
Cadmium	,,	,,	3	,,
Barium	,,	,,	2	,,
Lithium	,,	,,	1	,,

ELEMENTS COMPARED WITH BETELGEUSE.

Coincident.

1. Sodium with double line D.
2. Magnesium with triple line *b*.
3. Calcium with four lines.
4. Iron with three lines and E.
5. Bismuth with four lines.
6. Thallium (?).

Not coincident.

Hydrogen	compared	with	C	and F.
Nitrogen	,,	,,	3	lines.
Tin	,,	,,	5	,,
Lead	,,	,,	2	,,
Gold (?)				
Cadmium	,,	,,	3	,,
Silver	,,	,,	2	,,
Mercury	,,	,,	4	,,
Barium	,,	,,	2	,,
Lithium [s]	,,	,,	1	,,

[s] *Brit. Assoc. Rep.*, 1868, p. 144.

In Betelgeuse the hydrogen line F though faint seems also to have been since identified in one of the clusters.

Three elements are found in nearly all the stars that have been examined, viz. sodium, magnesium, and hydrogen. Iron is also frequently found. Sirius, Vega, and Pollux all give evidence of these four elements[h].

These results have shewn that the stars resemble our Sun in that they consist of an incandescent nucleus, surrounded by the absorbent vapours of elements, many of which are well known to us. On the 12th of May 1866, an unlooked-for event occurred which made it more than probable that prominences also are as much a feature of the economy of the stars as of our Sun. A faint 9th magnitude star in the Northern Crown suddenly attained a brightness surpassing that of a 2nd magnitude star, and then rapidly faded away till it again became of the 9th magnitude by the end of the month. On the 16th of May, when it was of about the 4th magnitude, Huggins examined its spectrum, and found that in addition to a spectrum analogous to that of the Sun, it shewed four bright lines, two of which were due to hydrogen. Their great brightness shewed that the luminous gas was hotter than the photosphere[i].

These facts lead to the startling hypothesis that the star had suddenly become wrapped in intensely luminous hydrogen. Several variable stars usually shew the hydrogen lines bright, and in η Argûs, according to Le Sueur, even D_3 appears, which is the yellow line seen so constantly in the prominences, a fact which seems to perfect the analogy between our Sun and the immeasurably distant stars[k].

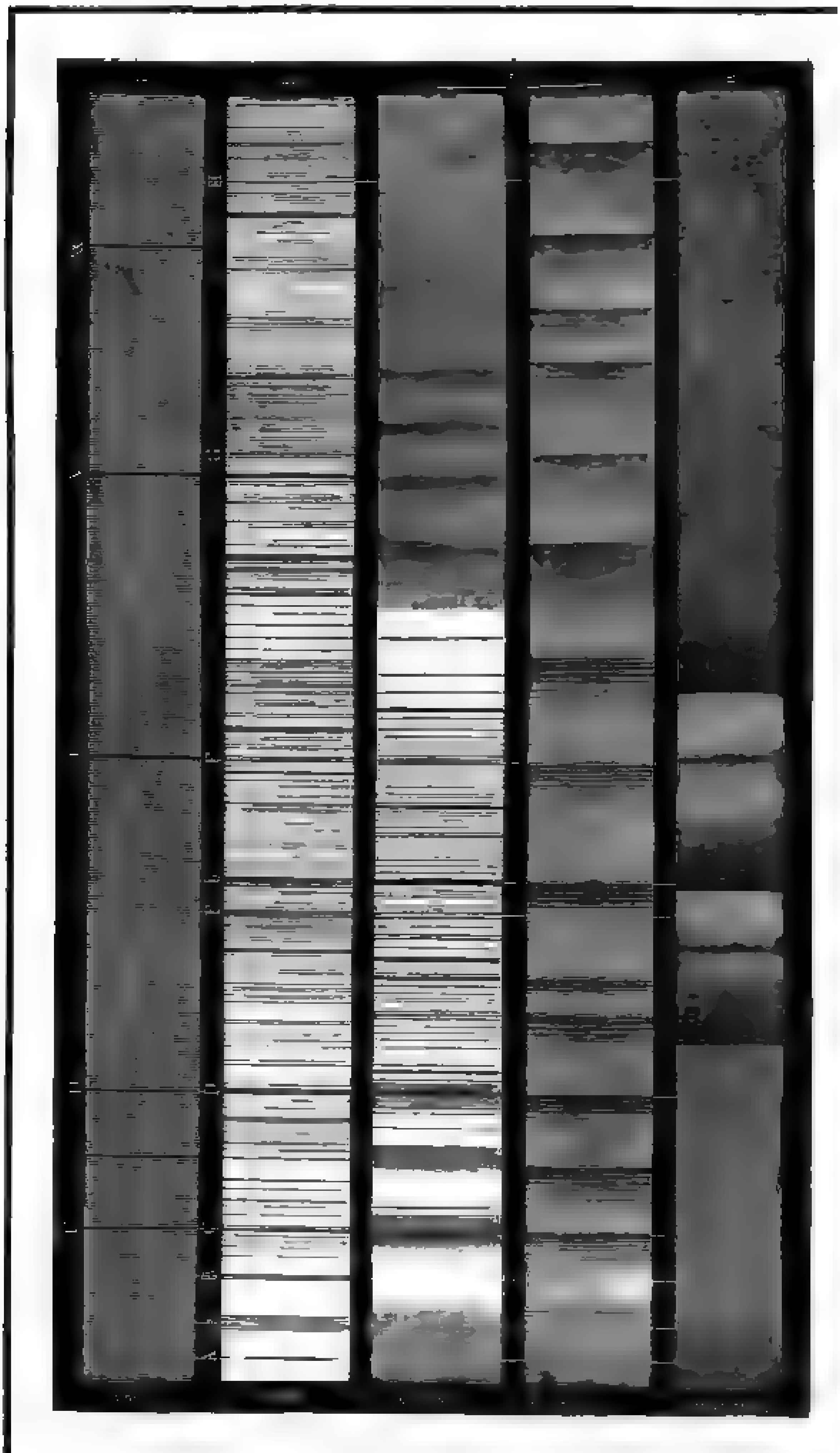
Whilst Huggins and Miller have thus been proving the identity in constitution of the stars and our Sun, Secchi has been engaged in investigating the differences which the stars exhibit *inter se*. The spectrum of almost every star visible to the unassisted eye in the latitude of Rome has been examined, and as a consequence of his observations Secchi groups them in 4 classes.

(1.) The white stars of which Sirius and Vega are the types, yielding spectra crossed by 4 broad dark lines due to hydrogen, and much broader than those in the solar spectrum. Other fainter

[h] *Beobachtungen angestellt auf der Sternwarte zu Bothkamp.* 1872.

[i] *Proc. Roy. Soc.*, vol. xv. p. 146. May 17, 1866.

[k] *Proc. Roy. Soc*, vol. xix. p. 18. June 16, 1870.



SECCHI'S STAR TYPES.

lines may be seen, but only with the most powerful and perfect instruments. The lines of sodium and magnesium however are sufficiently marked in the brightest stars to be easily identified.

(2.) The second class, embracing almost all the other lucid stars, consists of the yellow stars of which our sun is the example. In these spectra the dark lines are very fine and numerous, those of magnesium being often very distinctly marked. Arcturus, Capella, Pollux, and Aldebaran belong to this class.

(3.) The third type yields exceedingly beautiful spectra, crossed by 8 or more dark bands, very dark and sharp towards the violet end of the spectrum and gradually growing fainter towards the red end. *α* Herculis, the most superb of all, *α* Orionis, and Antares, are the principal stars of this type. The bands are resolvable into individual lines and their sharp edges seem to occupy the same position in all the stars of the type, two of them being marked by the lines D and *b*.

(4.) The fourth type are the red stars, which shew 3 large bands of light which alternate with dark spaces so distributed as to have the most luminous side towards the violet. Of these Secchi has examined all those in the catalogue of red stars given on pp. 587 *et seq.* of this work (*ante*) down to those of the 8th magnitude. The characteristics of these two last classes seem to point to the existence of compound bodies or metalloids in their atmospheres[1].

An exceedingly interesting investigation has been undertaken by Huggins, namely, the determination of the velocity of movement in the line of sight of the brightest stars, from the displacement of certain lines. For this, a very considerable dispersion is required, and hence in order that the spectrum may not be too much weakened, a telescope with a very large object-glass is needed, to collect sufficient light. In Secchi's work on star-types a slit might be dispensed with, as the image of the star formed by the cylindrical lens is almost a mathematical line; but in this a narrow slit is of primary importance, for otherwise the star might shift its position, and therefore the whole spectrum, including the particular line under examination, would likewise move in one direction or the other. A similar fictitious appearance of displacement will be caused if the light from the terrestrial sub-

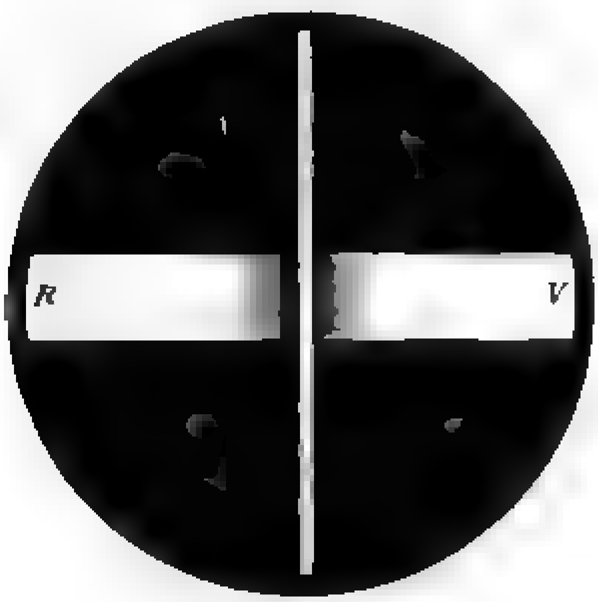
[1] *Brit. Assoc. Rep.*, 1868; and *Spettri prismatici delle Stelle fisse.* Roma, 1868.

stance which gives the comparison spectrum does not enter the slit perfectly at right angles to it. An additional difficulty is afforded in the case of stars of the first type by the breadth of the absorption lines in the star spectrum and the shaded appearance of their edges.

Fig. 285 shews the relative positions and appearances of the F line in Sirius and the hydrogen line H β given by a vacuum tube.

The fine equatorial of the Greenwich Observatory has been lately devoted to the same inquiry, with results agreeing fully as closely with those of Huggins as could have been anticipated, when the exceedingly difficult and delicate nature of the observation is borne in mind.

Fig. 285.



LINE *F* IN SPECTRUM OF SIRIUS COMPARED WITH HYDROGEN, SHEWING DISPLACEMENT.

The principal stars shewing a motion of approach are α Andromedæ, Pollux, α Ursæ Majoris, Arcturus, ϵ Bootis, Vega, α Cygni, α Pegasi. Those receding from us are Aldebaran, Capella, Rigel, Betelgeuse, Sirius, Castor, Procyon, Regulus, β, δ, ϵ, γ, and ζ Ursæ Majoris, Spica, and α Coronæ [m].

The rate of motion varies from about 12 to 55 miles per second. That of Sirius, the first tested by Huggins, is according to him from 18 to 26; from the Gre.nwich observations 25; and from Dr. Vogel's 40 miles per second [n].

[m] *Month. Not.*, vol. xxxvi. p. 316, May, 1876; *Proc. Roy. Soc.*, vol. xx. p. 386, June 13, 1872.

[n] *Beobachtungen angestellt auf der Sternwarte zu Bothkamp*, Part i. p. 34.

It will be seen that these observations tend on the whole to confirm the theory that the solar system is moving rapidly in the direction of *α* Herculis; for the majority of the stars observed in that portion of the heavens seem to be approaching, and most of those in the opposite half receding from us.

Nebulæ.—In August 1864, Huggins commenced the examination of these strange bodies, and was astonished to find no trace of the rainbow-tinted band that stars give, but in place of this, three bright lines only.

The long contested problem was solved at once. There was such a thing as a true nebula. The bright lines could only be due to luminous gas. One of the lines, the faintest, was coincident with F, the brightest with one of the close pair of green lines of nitrogen, the third has not been found to coincide with any strong line of any known element. Huggins felt at once the importance of examining as many nebulæ as possible, and he finds the following to be probably gaseous in constitution:—

TABLE OF NEBULÆ GIVING SPECTRA OF BRIGHT LINES.

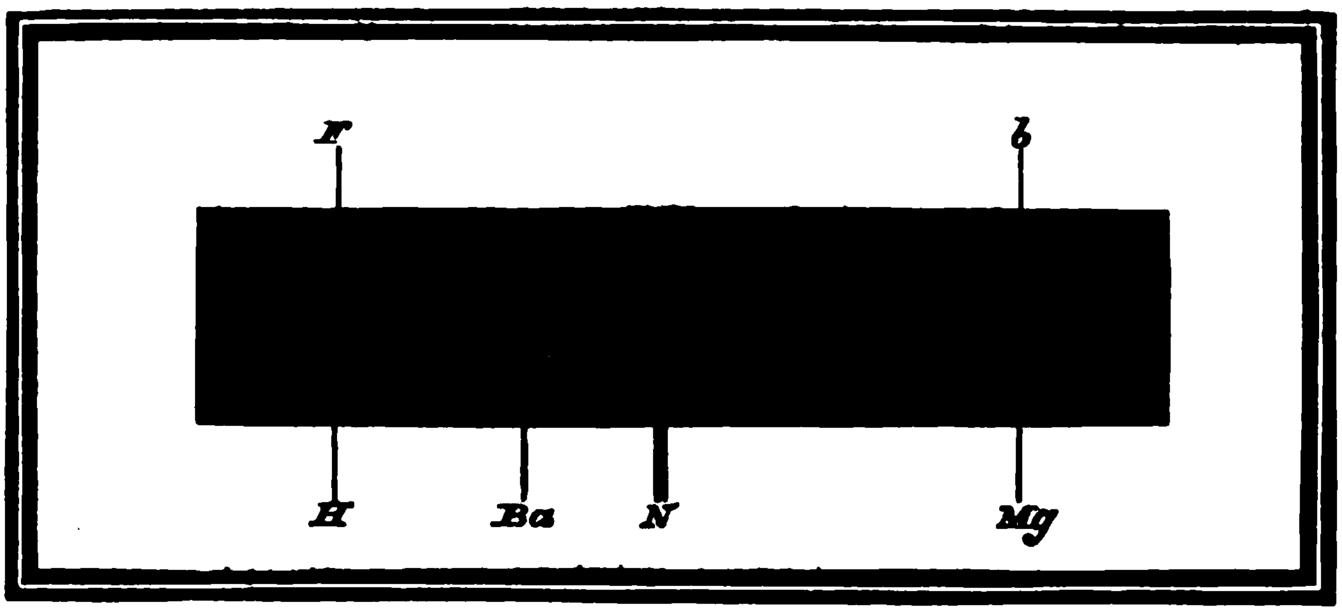
Number in Sir J. Herschel's Catalogue.	Other Designation.	Number in Sir J. Herschel's Catalogue.	Other Designation.
385	76 M.	4499	38 ♅ IV.
386	193 ♅ I.	4510	51 ♅ IV.
1179	Great Neb. in Orion.	4514	73 ♅ IV.
2102	37 ♅ IV.	4532	27 M.
2343	97 M.	4572	16 ♅ IV.
4234	5 Σ.	4627	192 ♅ I.
4373	37 ♅ IV.	4628	1 ♅ IV.
4390	73 ♅ IV.	4827	705 ♅ II.
4403	17 M.	4964	18 ♅ IV.
4447	57 M.		

All the gaseous nebulæ do not give the same number of lines. In the brightest nebulæ a fourth line still more refrangible is seen, which coincides with the bright hydrogen line H γ. The spectrum of every gaseous nebula consists probably of four lines, but in the faintest of the nebulæ it is difficult to see more

than the brightest line. Two lines agree with those of hydrogen, and shew its presence in the nebulæ, but the apparent coincidence of the brightest line with one of a pair of nitrogen lines does not prove that nitrogen exists in the nebulæ[o]. Some also give a faint continuous spectrum in addition to the bright lines[p].

The present Earl of Rosse has compared the observations made with his father's great telescope of the nebulæ and clusters examined

Fig. 286.



SPECTRUM OF THE NEBULA 37 ♅ IV. DRACONIS.

by Huggins, in order to inquire how far the classifications of the telescope and spectroscope agreed. The result is as follows:—

	Continuous spectrum.	Gaseous spectrum.
Clusters	10	0
Resolved, or resolved ?	5	0
Resolvable, or resolvable ?	10	6
Blue or green, no resolvability	0	4
No resolvability seen	6	5
	31	15
Not observed by Lord Rosse	10	4
	41	19[q]

Considering the extreme difficulty of telescopic observation of these objects, these results are remarkably accordant, and it may be safely assumed that those nebulæ giving a continuous spectrum are clusters of actual stars, while those giving only bright lines must be considered as simply masses of luminous gas.

[o] See *Proc. Roy. Soc.*, vol. xx. p. 385. June 13, 1872.

[p] *Phil. Trans.*, vol. cliv. p. 437, 1864; vol. clvi. p. 381, 1866.

[q] *Brit. Assoc. Rep.*, 1868, p. 149.

Meteors.—From the rapid motion and evanescent character of these objects spectroscopic observation is exceedingly difficult. Browning however succeeded in observing no less than seventy in August and November 1866, with an instrument constructed by himself for the purpose. This consisted simply of a direct-vision compound prism, and a plano-concave cylindrical lens; the latter being intended to diminish the apparent angle through which the meteors fell. The heads of the meteors gave spectra mostly continuous, though with frequent differences in the relative preponderance of the colours. In the tails, in every instance, orange-yellow light predominated, from which the presence of sodium may probably be inferred, a result confirmed by A. S. Herschel[1]. Secchi in 1868 succeeded in seeing the magnesium lines very distinctly in the spectrum of two meteors.

From these observations it may be concluded that meteors consist of incandescent solid bodies, but that the heat they are subjected to in passing through our atmosphere is often sufficient to volatilize such elements as sodium or magnesium.

[1] *Month. Not.*, vol. xxvii. p. 77. Jan. 1867.

CHAPTER III.

MISCELLANEOUS.

Determination of Wave-lengths.—Ångström's investigations.—The visible limits of the Solar Spectrum not its real limits.—Researches of Waterhouse and Abney.

DETERMINATION OF WAVE-LENGTHS.—It has always been a drawback in spectroscopic work that the measures obtained by different spectroscopes are not directly comparable. For the distances between individual lines do not always change in the same proportion as the entire length of the spectrum. Thus if two prisms similar in shape and size, one of flint glass and one of crown, be compared, not only will the spectrum given by the first be much the longer—about double in fact that given by the other—but it will be *proportionately* more spread out in the violet than that given by the crown glass.

But though the prismatic spectrum suffers from this inconvenience, there is another method of producing a spectrum which is free from it. If the light from the slit pass through a diffraction grating, that is, a piece of glass ruled with very fine close lines, instead of through a prism, a spectrum is produced in which the distance between any two lines is always proportional to the difference of the corresponding wave-lengths of light. In this manner Ångström and Thalén have mapped more than 1000 lines on a scale which permits the wave-length of any line to be read approximately to the hundred millionth of a millimetre. By the aid of these maps the measures taken with any spectroscope can easily be converted into wave-lengths. A scale of wave-lengths is marked off along one edge of a sheet of paper ruled into small squares, and a scale corresponding to that of the instrument at right angles to it. A series of careful measurements must then

be made of several of the principal Fraunhofer lines, spread as evenly as possible through the spectrum, and their wave-lengths ascertained from Ångström's map. Then a perpendicular is drawn on the paper from each measure to intersect that through the corresponding wave-length, and a curve as regular as possible is drawn through the points of intersection. Then if the position on the curve of any measure be found, the wave-length required will be directly opposite it on the scale of wave-lengths.

The following are Ångström's determinations of the wave-lengths of the principal Fraunhofer lines expressed in *tenthmetres*, a tenthmetre being the 1–10^{10} of a metre [a]:—

A	7600·9	b_2	5172·0
a	7185·0	b_3	5168·3
B	6866·8	b_4	5166·7
C	6561·8	F	4860·6
D_1	5895·0	G	4307·2
D_2	5889·0	h	4101·2
E	5269·0	H_1	3968·0
b_1	5183·0	H_2	3932·8 [b]

Photographing the Spectrum.—Photography has recently been applied to the production of maps of the spectrum with ever-increasing success. Sir W. Herschel at the beginning of the century proved that the spectrum does not really end where it ceases to be visible but continues much farther than the extreme red. Indeed, although this portion of the spectrum produces no effect on the eye as *light*, yet the maximum amount of *heat* is here. Later it has been shewn, notably by Stokes in his researches on Fluorescence, that the visible rays in the violet do not terminate the spectrum in that direction. This portion however can be rendered visible by means of certain substances, called fluorescent, which have the power of degrading, or lowering, the refrangibility of rays. But it also can be photographed, for this light has a rapid action on the salts of silver.

Mr. Rutherford of New York has photographed these ultra-violet

[a] In this particular case it is a small matter what the unit of reference is: I have therefore not converted these measures into their English equivalents, but by allowing the French "metre" to be mentioned here I would on no account have it supposed that I approve of that most arbitrary and unphilosophical system—the metric system of weights and measures. On the contrary I abhor it.—G. F. C.

[b] *Recherches sur le Spectre Solaire*, par A. J. Ångström.

rays, and the visible spectrum to a little below F. Until recently this was all that could be done, as the salts of silver were found to be quite insensitive to the red and yellow rays. But in 1873, Dr. Vogel, of the observatory at Bothkamp, discovered a method of rendering bromide of silver sensitive to rays of all colours. He thus describes the principle upon which he acts,—"I have found that bodies which absorb the yellow ray of the spectrum make bromide of silver sensitive to the yellow rays. In like manner I find bodies which absorb the red ray of the spectrum make bromide of silver sensitive to the red rays. For example, by the addition of *corallin*—which absorbs the yellow ray—to a bromide of silver film, it becomes as sensitive to the yellow ray as to the blue ray [c]."

The publication of this discovery has led to many spectroscopists and photographers making numerous experiments on the subject, and Captain Waterhouse has even obtained the maximum of photographic action in the yellow, by adding a solution of eosin to the collodion. Captain Abney has however obtained a *white* compound of silver, by adding a gum resin to the collodion; with this he has succeeded in obtaining an impression as far below A as A is below D [d]. Thus almost the entire range of the spectrum, as made known to us in any way whatever, has been mapped by the means of photography.

Both the portions ordinarily invisible, the ultra red and the ultra violet, shew absorption lines precisely similar in character to those seen in the visible part.

[c] Quoted in *Nature*, vol. ix. p. 113. Dec. 11, 1873.
[d] *Ast. Reg.* vol. xiv. p. 85. April, 1876.

BOOK XI.

ASTRONOMICAL BIBLIOGRAPHY.

CHAPTER I.

LIST OF PUBLISHED STAR CATALOGUES AND CELESTIAL CHARTS[a].

THE following is a list of all the principal Catalogues of Stars and other celestial objects which have ever appeared. The dates prefixed are in most cases those of actual publication, and where the works cited were issued in a separate form, the titles are as far as possible given in such a way as to enable intending purchasers living at a distance to notify in intelligible terms their wants to their booksellers[b].

CATALOGUES OF ISOLATED STARS.

B.C.

128. HIPPARCHUS. [Contains 1025 stars (excluding duplicates), observed at Rhodes, incorporated by Ptolemy into his Μεγάλη Σύνταξις, or *The Almagest*, and by him reduced to the epoch of 137 A.D. Last edition by Baily, in *Memoirs R.A.S.*, vol. xiii. p. 1. 1843. For a possible explanation of Ptolemy's Catalogue being so erroneous, see note by Drayson, *Month. Not.*, vol. xxviii. p. 207. May 1868.]

[a] This list is not intended to include every work issued, but merely the *principal*. The Catalogue of the library of the Pulkova Observatory (in W. Struve's *Description de l'Observatoire Astronomique Central*, fol. St. Pétersbourg, 1845) will be found useful to the bibliographer. A very useful *Reference Catalogue* of literary materials relating to Sidereal Astronomy, by E. B. Knobel, will be found in *Month. Not.*, vol. xxxvi. p. 365. 1876.

[b] Marked thus (*) are works which I have not had an opportunity of personally consulting, and the titles are therefore given at second-hand, and may be inexact. Every other work named in this chapter has been examined by myself at an enormous expenditure of time and labour.

A.D.

950 *circa.* ABD-AL-RAHMAN AL-SUFI. [A description of the heavens by a Persian Astronomer of Bagdad. Translated from Arabic into French and edited by H. C. F. C. Schjellerup as *Description des Étoiles Fixes.* 4to. St. Petersburg, 1874.]

*——. ABUL HASSAN ALI. [Contains 240 stars reduced to 622 A.D. Last edition by J. J. Sédillot. Paris, 1834.]

1437. ULUGH BEIGH. [Contains 1019 stars observed at Samarcand. Last edition by Baily, in *Memoirs* R.A.S., vol. xiii. p. 79. 1843.]

1602. TYCHO BRAHE, *Catalogus Stellarum Fixarum.* [Contains 777 stars observed at Uraniburg, reduced to the year 1600. 2nd edition, containing altogether 1005 stars, published by Kepler in 1627. Last edition by Baily, in *Memoirs* R. A.S., vol. xiii. p. 127. 1843.]

1618. WILLIAM, LANDGRAVE OF HESSE, aided by Rothmann and Byrgius, *Catalogus Stellarum Fixarum.* [Contains 368 stars; reduced to the year 1593. Last edition by Flamsteed, in *Hist. Cœlest.* vol. iii. p. 24. Fol. London, 1725.]

*1624. BARTSCHIUS, JACOBUS, *Planisphærium.* [Contains 136 southern stars; see remarks by Baily in *Memoirs* R.A.S., vol. xiii. p. 34. 1843.]

1679. HALLEY, *Catalogus Stellarum Australium.* [Contains 341 southern stars observed at St. Helena, reduced to 1677. Last edition by Baily, in *Memoirs* R.A.S., vol. xiii. p. 167. 1843.]

1690. HEVELIUS, J., of Danzig, *Catalogus Stellarum Fixarum.* [Contains 1564 stars, reduced to 1660 (end of). In his *Prodromus Astronomiæ.* Last edition by Baily, in *Memoirs* R.A.S., vol. xiii. p. 183. 1843.]

1725. FLAMSTEED, Rev. JOHN, *Catalogus Britannicus.* [In the *Historia Cœlestis.* Contains 3310 stars observed at Greenwich, and reduced to 1690. Last edition, considerably enlarged, by Baily in *Account of Flamsteed.* 4to. London, 1835.]

1725. SHARP, ABRAHAM. [Contains 265 southern stars observed at St. Helena; reduced to 1726. Published in Flamsteed's *Hist. Cœlest.*, iii. Fol. London, 1725.]

1757. LA CAILLE, N. L. [Contains 398 stars; reduced to Jan. 1, 1750. Published in his *Fundamenta Astronomiæ.* Last edition by Baily, in *Memoirs* R.A.S., vol. v. p. 93. 1833. Imperfect editions of this are in circulation: see Vince's *Astronomy.*]

*1763. LA CAILLE, N. L. [Contains 515 zodiacal stars; reduced to 1765. Edited, very carelessly, by Bailly, of Paris, and published in *Ephémérides des Mouvemens Célestes.* 1765–75.]

1763. LA CAILLE, N. L., *Cœlum Australe Stelliferum.* 4to. Paris. [Contains 1942 southern stars observed at the Cape.]

1773. BRADLEY, Rev. J. [Contains 389 stars observed at Greenwich; reduced to 1760. Published in the *Nautical Almanac.* 1773. Republished in 1798, by Hornsby, in his edition of Bradley's *Obs.*, vol. i. p. xxxviii.]

1774. MASKELYNE, Rev. N. [Contains 34 stars observed at Greenwich; reduced to 1770. Published in Maskelyne's *Greenwich Obs.*, vol. i., Appendix of Tables, p. 5.]

1775. MAYER, T. [Contains 998 stars observed at Göttingen; reduced to 1756. Edited by Lichtenberg, and published at Göttingen in Mayer's *Opera Inedita.* Last edition by Baily, in *Memoirs* R.A.S., vol. iv. p. 391. 1831.]

1786. Pigott, E., *Observations and Remarks on Stars ... suspected to be changeable.* *Phil. Trans.*, vol. lxxvi. p. 189. 1786. [Contains 50 stars known or suspected to be variable.]

*1792. De Zach, *Fixarum Præcipuarum Stellarum Catalogus Novus.* 4to. Gotha. [Contains 381 stars; reduced to 1800·0.]

1798. Herschel, W., *Catalogue of Flamsteed Stars.* Fol. Lond. [Contains stars selected from vol. ii. of Flamsteed's *Historia Cœlestis*, with notes by Sir W. Herschel and Errata by Miss C. Herschel.]

1800. Wollaston, Rev. F., *Catalogue of Circumpolar Stars* (260), reduced to 1800·0. 4to. Lond. [In the author's *Fasciculus Astronomicus.*]

1801. Lalande, J. De, *Catalogue.* [Contains 47,390 stars; reduced to 1800. Published in the *Histoire Céleste Française.* Last edition by Baily, for the British Association. 8vo. Lond., 1847.]

*1803. Cagnoli, A., *Catalogo di Stelle Boreali.* Published in *Mémoires de la Société Italienne des Sciences*, vol. x. [Contains stars observed at Modena.]

1803. Piazzi, G., *Præcipuarum Stellarum inerrantium Positiones Mediæ.* Fol. Panormi. [Contains 6748 stars observed at Palermo; reduced to 1801.]

*1805. Bode, J. E., *Catalogue de l'ascension droite et de la declinaison de 5505 étoiles.* 4to. Berlin. [Contains 5505 stars observed by Piazzi at Palermo and 372 nebulæ and clusters.]

*1806. De Zach. [Contains 1830 zodiacal stars observed at Seeberg.]

1807. Cagnoli, A., *Catalogue de 501 Étoiles.* [Observed at Modena. 8vo. Modène.]

*1807. Piazzi, G. [Contains 120 stars.]

1814. Piazzi, G., *Præcipuarum Stellarum inerrantium Positiones Mediæ.* 4to. Panormi. [Contains 7646 stars observed at Palermo; reduced to 1801·0. A sort of second edition of the Catalogue of 1803.]

1818. Bradley, Rev. J. [Contains 3222 stars observed at Greenwich; reduced to Jan. 1, 1755. Published by Bessel in his *Fundamenta Astronomiæ.* Fol. Regiomonti.]

1818. Pond, J., *Catalogue.* [Contains 400 stars; reduced to 1817·0. Published in *Greenwich Obs.*, 1814–16.]

*1819. Bessel, F. G. W., *Fundamentalsterne.* [Contains 36 important stars; reduced to 1815·0.]

1824. Fallows, Rev. F., *Catalogue of the Principal Fixed Stars.* *Phil. Trans.*, vol. cxiv. p. 457. 1824. [Contains 273 southern stars observed at the Cape of Good Hope; reduced to 1824·0.]

1827. Astronomical Society of London, *Catalogue.* *Memoirs* R.A.S., vol. ii. App. 1827. [Contains 2881 stars compiled from various sources; reduced to 1830·0.]

1827. Baily, F., *Catalogue of Zodiacal Stars.* 8vo. [Contains 1202 stars to the 7th magnitude, within 10° of the Ecliptic, selected from the *Ast. Soc. Catalogue*; reduced to 1830·0.]

1829. Pond, J., *Catalogue.* [Contains 720 stars observed at Greenwich; reduced to 1830·0. Published in *Greenwich Obs.*, 1829.]

1832. Rümker, C., *Preliminary Catalogue of Fixed Stars.* 4to. Hamburg. [Contains 632 southern stars; reduced to 1827·0.]

1833. Pond, J., *Catalogue of* 1112 *Stars.* Fol. Lond. [Stars observed at Greenwich; reduced to 1830·0.]

1833. BAILY, F., *List of 314 Stars known or supposed to have an annual proper motion exceeding 0·5″ of a great circle.* *Memoirs* R.A.S., vol. v. p. 158. 1833.

1835. ARGELANDER, F. G. A., *DLX. Stellarum Fixarum Positiones Mediæ.* 4to. Helsingforsiæ. [Contains 560 stars observed at Abo; reduced to 1830·0.]

1835. BRISBANE, Sir THOMAS, *Catalogue of 7385 Southern Stars.* [Observed at Paramatta, N.S.W. Ed. by W. Richardson. 4to. Lond.]

1835. JOHNSON, Lieut. M. J., *Catalogue of 606 Principal Fixed Stars in the Southern Hemisphere.* [Observed at St. Helena; reduced to 1830·0. Published by the H. E. I. Co. 4to. Lond.]

1838. GROOMBRIDGE, S., *Catalogue of Circumpolar Stars.* [Contains 4243 stars. 4to. Lond. Reduced to 1810·0. Edited by Airy.]

1838. HENDERSON, T., *Declinations of Principal Fixed Stars* (172). [Chiefly in the southern hemisphere; reduced to 1833·0.] *Memoirs* R.A.S., vol. x. p. 49. 1838.

1838. WROTTESLEY, Lord, *Right Ascensions of 1318 Stars.* [Observed at Blackheath; reduced to 1830·0.] *Memoirs* R.A.S., vol. x. p. 157. 1838.

1840. AIRY, G. B., *Catalogue of 727 Stars.* [Observed at Cambridge; reduced to 1830·0.] *Memoirs* R.A.S., vol. xi. p. 21. 1840.

*1840. SANTINI, G., *Positioni medie delle Stelle Fisse,* part i. stars (1744) from 0° to + 12°; part ii. stars (2348) from 0° to − 12°; observed at Padua; reduced to 1840·0. 4to.

1842. WROTTESLEY, Hon. J., *A Supplemental Catalogue of the Right Ascensions of 55 Stars.* [Reduced to 1830·0.] *Memoirs* R.A.S., vol. xii. p. 103. 1842.

1842. SANTINI, G., *Catalogue of 1677 Stars between the Equator and* + 10°. [Observed at Padua; reduced to 1840·0.] *Memoirs* R.A.S., vol. xii. p. 273. 1842.

*1843–52. RÜMKER, C., *Mittlere Oerter von 12,000 Fixsternen.* Oblong 4to. Hamburg. [Contains 11,978 stars observed at Hamburg; reduced to 1836·0.]

1844. HENDERSON, T., *Right Ascensions of the Principal Fixed Stars.* [Contains 174 stars; reduced to 1833·0.] *Memoirs* R.A.S., vol. xv.

1844. AIRY, G. B., *Catalogue of the places of 1439 Stars.* [Observed at Greenwich; reduced to 1840·0. Published in *Greenwich Obs.*, 1842, and separately.]

1844. TAYLOR, T. G., *General Catalogue of the Principal Fixed Stars.* 4to. Madras. [Contains 11,015 stars observed at Madras: reduced to 1835·0.]

1845. BRITISH ASSOCIATION, *Catalogue of Stars.* 4to. Lond. [Contains 8377 stars, compiled from various sources; reduced to 1850·0. Edited chiefly by Baily. This is commonly considered to be the most useful catalogue ever published, but it is now much out of date.]

1846. BESSEL, *Positiones Mediæ Stellarum Fixarum.* 4to. Petropoli. [Part i, between − 15° and + 15° equatorial regions of declination, containing 31,085 stars observed at Königsberg; reduced to 1825, by Weisse, at the expense of the Academy of Sciences of St. Petersburg, and edited by W. Struve.]

1846. PEARSON, Rev. W., *Catalogue of 520 Stars within 6° N. and S. of the Ecliptic.* [Reduced to 1830·0.] *Memoirs* R. A. S., vol. xv. p. 97. 1846.

1847. LA CAILLE, *Catalogue of 9766 Stars in the Southern Hemisphere.* 8vo. Lond. [Contains stars observed at the Cape of Good Hope; reduced to 1750·0. The reductions were carried on under the superintendence of Henderson, at the expense of H.M. Government.]

1848. TAYLOR, T. G., *Mean Places of 97 Principal Fixed Stars.* 4to. Madras. [Contains stars observed at Madras, 1843–7; reduced to 1845.]

1849. Airy, G. B., *Catalogue of* 2156 *Stars.* [Observed at Greenwich; reduced, some to 1840·0, the remainder to 1845·0. Published in *Greenwich Obs.*, 1847. Commonly called the *Greenwich* 12-*Year Catalogue.*]

1851. Fallows, Rev. F., *Catalogue.* [Contains 425 stars, observed at the Cape of Good Hope; reduced to 1830·0. Edited by Airy.] *Memoirs* R.A.S., vol. xix. p. 77. 1851.

1851. Main, Rev. R., *Proper Motions* [of 877 stars observed at Greenwich]. *Memoirs* R.A.S., vol. xix. p. 121. 1851.

1851–6. Cooper, E. J., *Catalogue of Stars near the Ecliptic.* 5 vols. 8vo. Dublin. [Observed at Markree in the years 1848–56: contains 60,066 stars.]

1852. Argelander, F. G. A., and Oeltzen, W., *Zonen Beobachtungen vom* 45° *bis* 80° *Nördlicher Declination.* [Contains 26,425 stars; reduced to 1842·0. Published in the *Annalen* of the Vienna Observatory. 8vo. Vienna.]

*1853. Jacob, W. S., *A Subsidiary Catalogue of* 1440 *B. A. C. Stars.* [Observed at Madras; reduced to 1850·0.]

1854. Fedorenko, I., *Positions Moyennes des Étoiles circompolaires.* 4to. St. Pétersbourg. [Contains 4673 circumpolar stars, from Lalande; reduced to 1790·0.]

1854. Wrottesley, Lord, *A Catalogue of the Right Ascensions of* 1009 *Stars.* [Observed at Wrottesley; reduced to 1850·0.] *Memoirs* R.A.S., vol. xxiii. p. 1. 1854.

1855. Bond, W. C., (1) *A Standard Catalogue of* 1123 *Stars* [between 0° and +1° of Decl.]: (2) *Zone Observations* [of 5500 stars between the equator and +0° 20′ of Decl.]. *Annals of Harvard Coll. Obs.*, vol. i. 4to. Cambridge, U.S.

1856. Airy, G. B., *Catalogue of* 1576 *Stars.* [Observed at Greenwich; reduced to 1850·0. Published in *Greenwich Obs.*, 1854.]

1856. Mädler, J. H., *Catalog der* 3222 *Bradleyschen sterne.* [Contains proper motions of all, and concluded Mean Places for 1850·0 derived from many standard catalogues; also nominal lists of all the stars from mags. 1–5 grouped in magnitudes. Published in vol. xiv. of the Dorpat *Beobachtungen.* 4to. Dorpat, 1856.]

1856. Pogson, N., *Catalogue of* 53 *known Variable Stars. Radcliffe Observations*, vol. xv. [Stars reduced to 1860·0.]

1857. Carrington, R. C., *Catalogue of* 3735 *Circumpolar Stars observed at Redhill.* Fol. Lond. [Reduced to 1855·0. Printed at the expense of H. M. Government.]

1857. Schwerd, G., *Stars observed at Speyer.* Printed at the end of Carrington's Redhill *Catalogue.* Fol. Lond. [Contains 680 circumpolar stars; reduced to 1828·0 and 1855·0; further revised by Oeltzen.]

1858. Santini, G. *Posizioni medie di* 2706 *Stelle.* 4to. Venezia, 1858. [Contains stars between −10° and −12° 30′; reduced to 1860. Republished from *Memorie dell' Istituto Veneto di Scienze*, vol. vii.]

1859. Argelander, F. G. A., *Bonner Sternverzeichniss, Erste Section.* 4to. Bonn. [Published in vol. iii. of the *Beobachtungen* of the Bonn Observatory: contains 110,984 stars, between −2° and +20°, observed at Bonn; reduced to 1855·0.]

1859. Robinson, Rev. T. R., *Places of* 5345 *Stars observed at Armagh.* 8vo. Dublin. [Reduced to 1840·0. Printed at the expense of H. M. Government.]

1859. RÜMKER, C., *Neue Folge Mittlerer Oerter von Fixsternen*. Hamburg. [Contains 3126 stars; reduced to 1850·0.]

1860. JACOB, Capt. W. S., *Catalogue of* 317 *B. A. C. Stars*. [Observed at Madras, for proper motions; reduced to 1855·0.] *Memoirs* R.A.S., vol. xxviii. p. 1. 1860.

1860. JOHNSON, M. J., *The Radcliffe Catalogue of* 6317 *Stars, chiefly Circumpolar*. 8vo. Oxford. [Stars observed at Oxford; reduced to 1845·0. Edited by the Rev. R. Main. This may be regarded as one of the most valuable catalogues published.]

1860. MAIN, Rev. R., *Proper Motions* [of 270 stars observed at Greenwich]. *Memoirs* R.A.S., vol. xxviii. p. 127. 1860.

1861. ARGELANDER, F. G. A., *Bonner Sternverzeichniss, Zweite Section*. 4to. Bonn. [Published in vol. iv. of the *Beobachtungen* of the Bonn Observatory: contains 105,075 stars, between + 20° and + 41°, observed at Bonn; reduced to 1855·0.]

1861. SAFFORD, T. H., *Catalogue of the Declinations of* 532 [zenith of Cambridge (U.S.)] *Stars*. *Memoirs Amer. Acad.*, vol. viii. part. i. p. 299. 1861. [Contains numerous titles of catalogues.]

1862. ARGELANDER, F. G. A., *Bonner Sternverzeichniss, Dritte Section*. 4to. Bonn. [Published in vol. v. of the *Beobachtungen* of the Bonn Observatory: contains 108,129 stars, between + 41° and + 90°, observed at Bonn; reduced to 1855·0.]

1862. SANTINI, G., *Posizioni medie di* 2246 *Stelle*. 4to. Venezia, 1862. [Contains stars between − 12° 30′ and − 15°; reduced to 1860·0. Republished from *Memorie dell' Istituto Veneto di Scienze*, vol. x.]

1863. BESSEL, F. G. W., *Positiones mediæ Stellarum Fixarum*. 4to. Petropoli. [Part ii, stars between + 15° and + 45°; contains 31,445 stars observed at Königsberg: reduced to 1825, by Weisse, at the expense of the Academy of Sciences of St. Petersburg, and edited by O. Struve.]

1863. SAFFORD, T. H., *Catalogue of Standard Polar and Clock Stars*. *Memoirs Amer. Acad.* vol. viii. part ii. p. 537. 1863. [Contains 121 stars reduced to 1855·0.]

1864. AIRY, G. B., *Greenwich 7-Year Catalogue*. [Contains 2022 stars observed at Greenwich. Published in App. to *Greenwich Obs.*, 1862.]

1864. SCHJELLERUP, H. C. F. C., *Stjernefortegnelse*. 4to. Kjobenhavn. [Contains 10,000 stars, between − 15° and + 15°, observed at Copenhagen.]

1865. CHAMBERS, G. F., *Catalogue of Variable Stars*. *Month. Not.*, vol. xxv. p. 208. May 1865. [Contains 128 stars, reduced to 1870·0.]

1866. LAMONT, J., *Verzeichniss von Æquatorial-Sternen*. [Contains 9412 stars between − 3° and + 3° of decl.; reduced to 1850. Published as *Supplementband* No. 5 to the *Annalen der Münchener Sternwarte*. 8vo. München.]

1867. SCHJELLERUP, H. C. F. C., *Genäherte Oerter der Fixsterne*. [Contains 6983 stars (various) mentioned in vols. 1–66 of *Ast. Nach.*] *Publications der Astronomischen Gesellschaft*, no. viii.

1867. ARGELANDER, F. G. A., *Mittlere Oerter von* 33,811 *Sternen*. 4to. Bonn. [Published in vol. vi. of the *Beobachtungen* of the Bonn Observatory: contains stars observed at Bonn 1845–67; reduced to 1855·0.]

*1869. COPELAND, R., and BÖRGEN, C., *Mittlere Oerter der in den Zonen* 0° *und* − 1° *der Bonner Durchmusterung enthaltenen Sternen*. [Contains 6595 stars to 9th mag. observed at Göttingen; reduced to 1875.]

1869. Lamont, J., *Verzeichniss von telescopischen Sternen.* [Contains 6323 stars between + 3° and + 9°; reduced to 1850. Published as *Supplementband* No. 8 to the *Annalen der Münchener Sternwarte.* 8vo. München.]

1869. Lamont, J., *Verzeichniss von telescopischen Sternen.* [Contains 4793 stars between − 3° and − 9°; reduced to 1850. Published as *Supplementband* No. 9 to the *Annalen der Münchener Sternwarte.* 8vo. München.]

*1869. Struve, O., *Ascensions Droites moyennes des Étoiles principales.* St. Petersburg. [Contains 374 principal stars observed at Pulkova, 1842–53; reduced to 1845.0.]

1870. Main, Rev. R., *The Second Radcliffe Catalogue.* 8vo. Oxford. [Contains 2386 stars observed at Oxford; reduced to 1860.]

1870. Airy, G. B., *New 7-Year Catalogue.* [Contains 2760 stars observed at Greenwich; reduced to 1864·0. Published in App. to *Greenwich Obs.* 1868.]

1870. Trettenero, *Posizioni medie di* 1425 *Stelle.* 4to. Venezia, 1870. [Contains stars between 0° and − 3°; reduced to 1860. Edited by Santini. Republished from *Memorie dell' Istituto Veneto di Scienze,* vol. xv.]

1871. Lamont, J., *Verzeichniss von telescopischen Sternen.* [Contains 3571 stars between + 9° and + 15°; reduced to 1850. Published as *Supplementband* No. 11 to the *Annalen der Münchener Sternwarte.* 8vo. München.]

1872. Lamont, J., *Verzeichniss von telescopischen Sternen.* [Contains 4093 stars between − 9° and − 15°; reduced to 1850. Published as *Supplementband* No. 12 to the *Annalen der Münchener Sternwarte.* 8vo. München, 1872.]

1872. Stone, E. J., *Mean Places of* 78 *Stars near the S. Pole, observed at the Cape of Good Hope.* [Reduced to 1871·0.] *Month. Not.*, vol. xxxiii. p. 55. Nov. 1872.

*1873. Gillis, J. M. [Contains 1693 stars, chiefly southern: reduced to 1850.0. Published as an Appendix to the *Washington Observations.*]

1873. Yarnall, M., *Catalogue of Stars observed at the United States Naval Observatory, Washington.* [Contains 10,658 stars; reduced to 1860. Published as Appendix III. to the *Washington Observations,* 1871.]

1873. Stone, E. J., *Cape Catalogue of* 1159 *Stars.* 8vo. Cape Town. [Observed at the Cape of Good Hope, 1856-61: reduced to 1860.]

1874. Ellery, R. J., *First Melbourne General Catalogue* [of 1227 stars observed at Melbourne; reduced to 1870·0]. 4to. Melbourne.

1874. Lamont, J., *Verzeichniss von telescopischen Sternen.* [Contains 5563 stars North of + 15° and South of − 15°; reduced to 1850. Published as *Supplementband* No. 13 to the *Annalen der Münchener Sternwarte.* 8vo. München. This volume also contains, as supplements to previous catalogues, the places of 3466 stars.]

1875. Stone, E. J., *Proper Motions of* 406 *Southern Stars. Memoirs* R.A.S., vol. xlii. p. 129. 1875.

1875. Winlock, J., *Right Ascensions of Fundamental Stars observed at Harvard College Observatory* 1872-3. *Ast. Nach.*, vol. lxxxvii. Nos. 2069–70, Dec. 29, 1875. [Contains 355 stars; reduced to 1873·0.]

CATALOGUES OF DOUBLE STARS.

1782. HERSCHEL, W., 1st *Catalogue of Double Stars. Phil. Trans.*, vol. lxxii. p. 112. 1782. [Contains 269 stars.]

1785. HERSCHEL, W., 2nd *Catalogue of Double Stars. Phil. Trans.*, vol. lxxv. p. 40. 1785. [Contains 434 stars.]

1822. HERSCHEL, Sir W., 3rd Catalogue, *Places of* 145 *New Double Stars. Memoirs* R.A.S., vol. i. p. 166. 1822.

1822. STRUVE, F. G. W., *Catalogus Stellarum Duplicium.* 4to. Dorpati. [Contains 795 stars observed at Dorpat; reduced to 1820·0.]

1822. SOUTH, J., *Observations of Double or Compound Stars. Memoirs* R.A.S., vol. i. p. 109. 1822. [Contains 477 stars observed in London; reduced to 1821·0.]

1825. HERSCHEL, J. F. W., and SOUTH, J., *Observations of* 380 *Stars. Phil. Trans.*, vol. cxiv. part iii. p. 1. 1825.

1826. HERSCHEL, J. F. W., 1st Catalogue, *Approximate Places of* 321 *Stars. Memoirs* R.A.S., vol. ii. p. 475. 1826.

1826. SOUTH, J., *Observations of* 458 *Double and Triple Stars,* [and a re-examination of 43 old double stars.] *Phil. Trans.*, vol. cxvi. p. 1. [And as a separate publication.]

1826. STRUVE, F. G. W., *Comparison of Observations on Double Stars.* [Being notes on 56 Herschel and South stars re-observed at Dorpat.] *Memoirs* R.A.S., vol. ii. p. 443. 1826.

1827. STRUVE, F. G. W., *Catalogus Novus Stellarum Duplicium et Multiplicium.* Fol. Dorpati. [Contains 3112 stars observed at Dorpat; reduced to 1826·0.]

1829. DUNLOP, J., *Approximate Places of Double Stars. Memoirs* R.A.S., vol. iii. p. 257. 1829. [Contains 253 stars observed at Paramatta, N.S.W.]

1829. HERSCHEL, J. F. W., 2nd Catalogue, *Approximate Places and Descriptions of* 295 *Stars. Memoirs* R.A.S., vol. iii. p. 47. 1829.

1829. HERSCHEL, J. F. W., 3rd *Catalogue of* 384 *Double and Multiple Stars. Memoirs* R.A.S., vol. iii. pp. 177 and 201. 1829.

1829. HERSCHEL, J. F. W., *Comparative Catalogue of* 284 *Double Stars. Memoirs* R.A.S., vol. iii. p. 190. 1829. [Stars observed at Dorpat and Slough.]

1831. HERSCHEL, J. F. W., 4th Catalogue, *Mean Places of* 1236 *Double Stars. Memoirs* R.A.S., vol. iv. p. 331. 1831.

1831. LABAUME, B., *Catalogue of* 195 *Double Stars. Memoirs* R.A.S., vol. iv. p. 165. [Stars from Lalande's *Histoire Céleste,* reduced to 1800·0.]

1833. HERSCHEL, J. F. W., *Micrometrical Measures of* 364 *Double Stars. Memoirs* R.A.S., vol. v. p. 13. 1833. [Contains a blank form for use of observers of double stars.]

1833. HERSCHEL, Sir J. F. W., 5th *Catalogue of Double Stars. Memoirs* R.A.S., vol. vi. p. 1. 1833. [Contains 2007 stars, 1304 being new.]

1833. DAWES, W. R., *Observations of Double Stars. Memoirs* R.A.S., vol. v. p. 139. 1833. [Contains important comparative observations of 9 binary stars.]

1835. DAWES, W. R., *Micrometrical Measurements of* 121 *Double Stars.* [Observed at Ormskirk.] *Memoirs* R.A.S., vol. viii. p. 61. 1835.

1835. HERSCHEL, Sir J. F. W., *Micrometrical Measures of Double Stars. Memoirs* R.A.S., vol. viii. p. 37. 1835. [Contains 377 stars.]

1836. HERSCHEL, Sir J. F. W., 6th *Catalogue of Double Stars. Memoirs* R.A.S., vol. ix. p. 193. 1836. [Contains 286 stars, 105 being new.]

1837. STRUVE, F. G. W., *Stellarum Duplicium et Multiplicium Mensuræ Micrometricæ, per magni Fraunhoferi tubum*, &c. Fol. Petropoli. [Contains 3112 stars observed at Dorpat.]

1843. STRUVE, F. G. W., *Catalogue de 514 étoiles doubles et multiples découverts à Poulkova et Catalogue de 256 étoiles doubles principales.* Fol. St. Pétersbourg.

1847. MÄDLER, J. H., *Untersuchungen über die Fixstern-systeme*, 2 vols. Fol. Leipzig, 1847. [Contains a very large collection of double star measures from various sources brought together to show movement or the contrary.]

1847. HERSCHEL, Sir J. F. W., 7th Catalogue, *Reduced Observations. Res. of Ast. Obs.*, p. 165. 4to. Lond. [Contains 2102 southern stars.]

*1849. MÄDLER, J. H., *Tabulæ Generales Stellarum Duplicium.* [Contains about 600 of Struve's stars, combined for solar motion.]

1849. JACOB, W. S., *Catalogue of Double Stars. Memoirs* R. A. S., vol. xvii. p. 179. 1849. [Contains 244 stars observed at Poona, 1845–8, and embraces a small Catalogue previously published in *Memoirs* R. A. S., vol. xvi.]

1850. STRUVE, O., *Catalogue revu et corrigé des étoiles doubles et multiples decouvertes à Poulkova. Memoires de l'Academie de St. Pétersbourg*, 6th ser., vol. v. [Contains 514 stars; reduced to 1850, and is a 2nd edition of the Catalogue which appeared in 1843 in W. Struve's name.]

1851. DAWES, W. R., *Micrometrical Measurements of 221 Double Stars.* [Made at Ormskirk.] *Memoirs* R. A. S., vol. xix. p. 191. 1851.

1852. STRUVE, F. G. W., *Stellarum Fixarum Positiones Mediæ.* Fol. Petropoli. [Contains 2874 stars observed at Dorpat; reduced to 1830.]

1854. FLETCHER, I., *Results of Micrometrical Measures. Memoirs* R. A. S., vol. xxii. p. 167. 1854. [Contains 51 stars.]

1856. DEMBOWSKI, Baron H., *Ast. Nach.*, vols. xlii–iv, Nos. 999–1036, various numbers during 1856. [Contains 127 stars observed at Naples.]

1856. MÄDLER, J. H. [Contains numerous stars, from Struve, observed 1846–51. Published in Dorpat *Beobachtungen*, vol. xiii. A second series will be found in vol. xv. part 1.]

1857. POWELL, E. B., *Observations of Double Stars. Memoirs* R.A.S., vol. xxv. p. 55. 1857. [Contains 108 stars observed at Madras.]

1857–9. CLARK, A., *New Double Stars. Month. Not.*, vol. xvii. p. 257, July 1857; vol. xx. p. 55, Dec. 1859. [Contains 20 new double stars discovered by A. C., with copious notes by Dawes.]

1859. SECCHI, A., *Misure di Stelle doppie.* [Contains 1321 stars (whereof 1114 are from Struve), observed for movement. Published in *Memorie dell Osservatorio del Collegio Romano*, No. v.]

1859. STRUVE, O., *Some lately discovered Double Stars. Month. Not.*, vol. xx. p. 8. Nov. 1859. [Contains 9 new double stars discovered by O. S., with copious notes.]

1860. JACOB, Capt. W. S., *Micrometrical Measures of 120 Double or Multiple Stars.* [Observed at Madras, 1856–8.] *Memoirs* R.A.S., vol. xxviii. p. 13. 1860.

1861. WROTTESLEY, Lord, *A Catalogue of the Positions and Distances of 398 Double Stars. Memoirs* R.A.S., vol. xxix. p. 85. 1861. [Places reduced to 1860·0.]

1864. DEMBOWSKI, Baron H., *Beobachtungen von Doppelsternen. Ast. Nach.*, vol. lxii. Nos. 1473-5. May 28, 1864. [Contains 171 stars observed at Gallarate.]

1864. POWELL, E. B., *Second Series of Observations. Memoirs* R.A.S., vol. xxxii. p. 75. 1864. [Contains 56 double stars observed at Madras.]

1864. DAWES, W. R., *A List of New Double Stars. Month. Not.*, vol. xxiv. p. 117. March 1864. [Contains 15 new double stars discovered by W. R. D., with copious notes.]

*1865. ENGELMANN, R., *Messungen von 90 Doppelsternen.* [Observed at Leipzig.]

1865. ROMBERG, H., *Double Stars taken from Struve's Catalogue.* [Contains measurements of 65 stars made at Mr. J. G. Barclay's Observatory, Leyton, 1862–4; reduced to 1865·0. Published in *Leyton Astronomical Obs.*, vol. i. p. 1. 4to. Lond., 1865.]

1867. DAWES, W. R., *Catalogue. Memoirs* R.A.S., vol. xxxv. p. 137. 1867. [Contains 2135 stars observed at various places; reduced to 1850.]

1867. HERSCHEL, Sir J. F. W., *Synopsis of all Sir W. Herschel's Doubles.* [812 in number; reduced to 1880.] *Memoirs* R.A.S., vol. xxxv. p. 21. [See corrections by Sir J. H. in *Month. Not.*, vol. xxviii. p. 151, March 1868; and by Burnham, *Month. Not.*, vol. xxxiv. p. 98. Jan. 1874.]

1868. ENGELMANN, R., *Doppelstern Messungen. Ast. Nach.*, vol. lxx. Nos. 1673–6. Jan. 17, 1868. [Contains 153 stars (chiefly Struve's) observed at Leipzic.]

1868. HERSCHEL, Sir J. F. W., *Additional Identifications of Double Stars ... with a List of Errata. Month. Not.*, vol. xxviii. p. 151. March 1868. [Contains a long series of corrigenda for Sir J. H.'s edition of Sir W. H.'s Catalogue in *Memoirs* R.A.S., vol. xxxv. p. 21. 1867.]

1869. DEMBOWSKI, Baron H., *Ast. Nach.*, vol. lxxiii. Nos. 1735–6. Jan. 22, 1869. [Contains 163 stars observed at Gallarate.]

1870. TALMAGE, C. G., *Double-Star Observations.* [Contains measurements of 218 stars made at Mr. J. G. Barclay's Observatory, Leyton, 1865–9; reduced to 1870·0. Published in *Leyton Astronomical Obs.*, vol. ii. p. 1. 4to. Lond., 1870.]

1873. BURNHAM, S. W., *Catalogues. Month. Not.*, vol. xxxiii. pp. 351 and 437. March and May 1873. [Contain 81 and 25 new Doubles discovered at Chicago, U.S.; reduced to 1870.]

1873. BURNHAM, S. W., *Third Catalogue. Month. Not.*, vol. xxxiv. p. 59. Dec. 1873. [Contains 76 new Doubles discovered at Chicago, U.S.; reduced to 1880.]

1873. TALMAGE, C. G., *Double-Star Observations.* [Contains measurements of 91 stars made at Mr. J. G. Barclay's Observatory, Leyton, 1870–2; reduced to 1870·0. Published in *Leyton Astronomical Obs.*, vol. iii. part i. p. 1. 4to. Lond., 1873.]

1874. DEMBOWSKI, Baron H., *Ast. Nach.*, vol. lxxxiii. No. 1979. March 18, 1874. [Contains 34 stars observed at Gallarate.]

1874. BURNHAM, S. W., *Fourth Catalogue. Month. Not.*, vol. xxxiv. p. 382. June 1875. [Contains 47 new Doubles discovered at Chicago, U.S.; reduced to 1880.]

1874. BURNHAM, S. W., *Fifth Catalogue. Month. Not.*, vol. xxxv. p. 31. Nov. 1874. [Contains 71 new Doubles discovered at various American Observatories; reduced to 1880.]

1875. HERSCHEL, Sir J. F. W., *Catalogue of 10,300 Multiple and Double Stars. Memoirs* R.A.S., vol. xl. p. 1. 1875. [From various sources; reduced to 1830. Edited by Main and Pritchard.]

1875. Wilson, J. M., and G. M. Seabroke, *Catalogue of Micrometrical Measurements of Double Stars. Memoirs* R. A. S., vol. xlii. p. 59. 1875. [Contains 467 stars observed at Rugby.]

1875. Gledhill, J., *Measures of* 484 *Double Stars made at Halifax. Memoirs* R. A. S., vol. xlii. p. 101. 1875.

1875. Burnham, S. W., *Sixth Catalogue. Ast. Nach.*, vol. lxxxvi. No. 2062. Nov. 5, 1875. [Contains 90 new Doubles discovered at Chicago, U.S.; reduced to 1880.]

1876. Burnham, S. W., *A Catalogue of Red Double Stars. Month. Not.*, vol. xxxvi. p. 331. May 1876. [Contains 102 stars within 121° of N.P.D., which are not in Schjellerup's *Catalogue*, 2nd ed.]

1876. Burnham, S. W., *Seventh Catalogue. Ast. Nach.*, vol. lxxxviii. No. 2103. Aug. 31, 1876. [Contains 46 new Doubles discovered at Chicago, U.S.; reduced to 1880.]

MISCELLANEOUS CATALOGUES.

1844. Smyth, Admiral W. H., *Cycle of Celestial Objects*, 2 vols. 8vo. Lond. [Contains 580 double stars, 20 binary systems, 80 triple and multiple stars, and 170 clusters and nebulæ, observed at Bedford; reduced to Jan. 1, 1840. A most interesting but very scarce work.]

1859. Webb, Rev. T. W., *Celestial Objects for Common Telescopes.* 18mo. Lond. [A popular handbook, on the plan of the preceding; most useful. 3rd edition, 1874.]

CATALOGUES OF COMETS.

1783. Pingré, A., *Cométographie.* 4to. Paris. [A most elaborate history of all recorded comets.]

1847. Galle, J. G. [Published in Encke's edition of Olbers's *Abhandlung über die leichteste und bequemste Methode die Bahn eines Cometen zu berechnen.* 8vo. Weimar, 1847. Contains orbits of 178 comets. Galle published a supplement to this in 1864, appended to his new edition of the *Abhandlung.*]

1847. Jahn, G. A., *Verzeichniss aller bis zum Jahre* 1847 *berechneten Kometenbahnen.* Oblong 4to. Leipzig, 1847. [Contains orbits of 195 comets.]

1852. Cooper, E. J., *Cometic Orbits.* 8vo. Dublin. [Contains 198 comets, with copious notes appended thereto. No less than 754 distinct sets of elements are given.]

1852. Hind, J. R. [Contains 231 comets: appended to the author's *Descriptive Treatise on Comets.* 12mo. London.]

1864. Carl, P., *Repertorium der Cometen Astronomie.* 8vo. München, 1864. [A most valuable and complete cyclopædia of cometary observations and elements.]

1871. Williams, J., *Observations of Comets*, from B.C. 611 to A.D. 1640. 4to. Lond. [Contains 373 comets observed in China.]

1876. Chambers, G. F., *Catalogues of Comets.* [Contains Tables of 329 calculated comets, and an historical abstract of observations of 521 other comets, being all on record. See pp. 335–430, *ante.*]

CATALOGUES OF NEBULÆ (INCLUDING CLUSTERS).

1716. HALLEY, E., *An Account of several Nebulæ or Lucid Spots. Phil. Trans.*, vol. xxix. p. 390. [Contains an account of 6 nebulæ.]

1735. DERHAM, Rev. W., *Observations of the Appearances among the Fixed Stars, called Nebulous Stars. Phil. Trans.*, vol. xxxviii. p. 70. [Contains 16 nebulæ.]

*1761. LA CAILLE, *Sur les Étoiles Nebuleuses du Ciel Austral.* [Contains 42 nebulæ observed at the Cape of G. H.] *Mém. Acad. des Sciences*, 1755, p. 194.

*1784. MESSIER, *Catalogue des Nebuleuses et des Amas d'Étoiles.* [Contains 103 nebulæ.] Published in the *Connaissance des Temps*, 1784, pp. 227, 268.

1786. HERSCHEL, W., *Catalogue of* 1000 *New Nebulæ.* [Observed at Slough.] *Phil. Trans.*, vol. lxxvi. p. 457. 1786.

1789. HERSCHEL, W., *Catalogue of a Second* 1000 *of New Nebulæ.* [Observed at Slough.] *Phil. Trans.*, vol. lxxix. p. 212. 1789.

1802. HERSCHEL, W., *Catalogue of* 500 *New Nebulæ.* [Observed at Slough.] *Phil. Trans.*, vol. xcii. p. 477. 1792.

1828. DUNLOP, J., *Catalogue of Nebulæ. Phil. Trans.*, vol. cxviii. p. 113. 1828. [Contains 629 nebulæ observed at Paramatta, N.S.W. Engravings of 27.]

1833. HERSCHEL, Sir J. F. W., *Observations of Nebulæ and Clusters. Phil. Trans.*, vol. cxxiii. p. 359. 1833. [Contains 2307 nebulæ observed at Slough, whereof about 500 were new; reduced to 1830·0. Engravings of 67.]

1837. LAMONT, J., *Ueber die Nebelflecken.* 4to. München. [Remarks on nebulæ generally, with notes on and rough lithographic sketches of 11 nebulæ in particular.]

1841. SMITH, H. L., and MASON, E. P., *Observations on Nebulæ with a* 14*-ft. Reflector. Trans. Amer. Phil. Soc.*, 2nd series, vol. vii. pp. 165–213. 1841. [Contains observations and detailed notes on 4 nebulæ, with figs. thereof, black on white ground. The nebulæ are h 1991, 2008, 2092, and 2093.]

1844. ROSSE, Earl of, *Observations on some of the Nebulæ. Phil. Trans.*, vol. cxxxiv. p. 321. 1844. [Engravings (5), and notes on nebulæ observed at Birr Castle.]

1847. HERSCHEL, Sir J. F. W., *Observations of Nebulæ.* [Contains 1708 nebulæ observed at the Cape of Good Hope; reduced to 1830. Engravings of 60. Published in *Results of Astronomical Observations, &c.*, p. 1. 4to. Lond., 1847.]

1847. HERSCHEL, Sir W., *Places and Descriptions of* 8 *Nebulæ.* [Published in his son's *Results of Astronomical Observations*, p. 128.]

1850. ROSSE, Earl of, *Observations on the Nebulæ. Phil. Trans.*, vol. cxl. p. 499. 1850. [Engravings (17), and notes on nebulæ observed at Birr Castle.]

1853. LAUGIER, E., *Nouveau Catalogue de Nebuleuses. Compt. Rend.*, vol. xxxvii. p. 874. Dec. 12, 1853. [Contains 53 nebulæ observed at Paris; reduced to 1850·0. Nebulæ were selected which had defined centres, so as to secure good observations of places such as might hereafter become available for investigations as to proper motion.]

1856. D'ARREST, *Resultate aus Beobachtungen der Nebelflecken. Abhandlung der Königl. Sächs. Gesellschaft der Wissenschaften.* [Contains about 230 nebulæ observed at Leipzig; reduced to 1850·0.]

1862. AUWERS, A., *Verzeichnisse von Nebelflecken und Sternhaufen.* Fol. Königsberg. [Contains about 2600 nebulæ (some duplicate), chiefly from Sir W. Herschel's

Catalogues; reduced to 1830. In this work is reprinted Messier's old but important catalogue of 101 nebulæ.]

1862. Rosse, Earl of, *Selected Observations of Nebulæ*. *Phil. Trans.*, vol. cli. p. 709. 1862. [Contains notes on 989 nebulæ observed at Birr Castle. Engravings of 43.]

1862. Auwers, A., *Verzeichniss der Oerter von vierzig Nebelflecken*. *Ast. Nach.*, vol. lviii. No. 1392. Nov. 14, 1862. [Contains 40 Herschelian nebulæ observed at Königsberg.]

1863. Bond, G. P., *List of New Nebulæ*. *Ast. Nach.*, vol. lxi. No. 1453. Dec. 18, 1863. [Contains 33 unrecorded nebulæ discovered at various times at Harvard College Observatory.]

1864. Herschel, Sir J. F. W., *Catalogue of Nebulæ and Clusters of Stars*. *Phil. Trans.*, vol. cliv. p. 1. 1864. [Contains 5079 objects (all then known). A grand work in every sense.]

1865. Auwers, A., *Beobachtungen von Nebelflecken*. [Contains places for 1860·0 of 40 nebulæ, chiefly Herschelian. Published in vol. xxxv. of the *Astronomische Beobachtungen* of the Königsberg Observatory. Fol. Königsberg, 1865.]

1867. Vogel, H. C., *Beobachtungen von Nebelflecken und Sternhaufen*. 8vo. Leipzic, 1867. [Contains 100 Herschelian nebulæ re-observed at Leipzig.]

1867. Marth, A., *Catalogue of New Nebulæ*. *Memoirs* R.A.S., vol. xxxvi. p. 53. 1867. [Contains 600 nebulæ, nearly all discovered with Mr. Lassell's telescope at Malta.]

1867. Lassell, W., *Observations of Remarkable Nebulæ*. *Memoirs* R.A.S., vol. xxxvi. p. 39. 1867. [Contains notes on 37 nebulæ observed at Malta, with engravings of all.]

1867. D'Arrest, H. L., *Siderum Nebulosorum Observationes Havnienses*. 4to. Havniæ. [Contains 1942 nebulæ, whereof 390 are new; reduced to 1861.]

1868. Schmidt, J. F. J., *Mittlere Oerter von Nebeln*. *Ast. Nach.*, vol. lxx. No. 1678. Feb. 12, 1868. [Contains 110 nebulæ observed for places.]

1871–3. Stephan, E., *Nebulæ Discovered and Observed at Marseilles*. *Month. Not.*, vol. xxxii. pp. 23 and 231, Nov. 1871 and March 1872; vol. xxxiv. p. 75, Dec. 1873. [Three catalogues containing respectively 40, 19, and 15 nebulæ.]

1875. Schultz, H., *Month. Not.*, vol. xxxv. p. 135. Jan. 1875. [Contains 512 nebulæ from various sources observed at Upsala; reduced to 1865·0. Important descriptive notes of the Herschelian type are given. There is a 4to. edition, entitled *Micrometrical Observations of* 500 *Nebulæ*, Upsala, 1874, in English throughout. This latter is reprinted from *Nova Acta Regiæ Societatis Scientiarum Upsaliensis*, 3rd series, vol. ix.]

1875. Schönfeld, E., *Micrometrische Ortsbestimmungen von Nebelflecken und Sternhaufen*. [Contains valuable original observations of more than 600 Herschelian and other nebulæ; reduced to 1865·0. Published in vols. i–ii. of the *Astronomische Beobachtungen* of the Mannheim Observatory. 4to. Mannheim, 1862, and Carlsruhe, 1875.]

1876. Stephan, E. Published in *Comptes Rendus*, vol. lxxxiii. p. 328, July 31, 1876. [Contains 23 new nebulæ discovered at Marseilles.]

ATLASES, CHARTS, ETC.

1603. BAYER, J., *Vranometria, omnium Asterismorvm continens schemata novâ Methodo delineata.* Fol. Ulmæ. [The earliest important maps of the stars; 51 plates in all.]

1627. SCHILLER, J., and others, *Cœlvm Stellatvm Christianvm.* Oblong fol. Avgvstæ Vindelicorvm. [A curious and very rare old work, depicting numerous saints enshrined amongst the stars. This is rather a revision of Bayer than an independent work.]

1690. HEVELIUS, J., *Firmamentum Sobieskianum, sive Uranographia.* Fol. Gedani. [Contains 54 plates and 2 hemispheres. Some new constellations are introduced.]

1729. FLAMSTEED, Rev. J., *Atlas Cœlestis.* Fol. Londini. [Contains 27 maps. Last edition, 1781. Universally used during the last century.]

1742. DOPPELMAIER, J. G., *Atlas Cœlestis.* Fol. Norimbergæ. [Contains 34 maps and plates.]

1776. FLAMSTEED, Rev. J., *Atlas Celestis.* Edited for the *Academie des Sciences* at Paris, by J. Fortin. 2nd ed. Paris. [Contains 30 maps and charts.]

1782. FLAMSTEED, Rev. J., *Representation des Astres... suivant l'Atlas Céleste de Flamsteed... corrigée, par J. E. Bode.* Oblong 4to. Berlin, 1782. [Contains 34 maps and charts.]

1801. BODE, J. E., *Uranographia, sive astrorum descriptio 20 tabulis æneis incisa.* Fol. Berolini. [Exhibits 17,240 stars; epoch 1801.]

1811. WOLLASTON, F., *A Portraiture of the Heavens as they appear to the Naked Eye.* Fol. Lond., 1811. [Contains 10 plates; stars, black on white ground.]

1822. JAMIESON, A., *A Celestial Atlas, comprising a systematic display of the Heavens in 30 Maps.* Oblong 4to. [Contains a large amount of information and no little nonsense.]

1822. HARDING, C. L., *Atlas Novus Cœlestis continens stellas inter polum borealem et 30mum grad. declinationis Australis adhuc observatas.* Gottingæ. [Contains above 40,000 stars down to mag. 9, and is executed with evident care. Last edition, Halle, 1856.]

1824. GREEN, J., *Astronomical Recreations, or Sketches of the Relative Positions and Mythological History of the Constellations.* 4to. Philadelphia. [Contains 19 plates, whereof 17 give the constellations reduced from Bode's Atlas, coloured by hand, and with stars to mag. 4. The historical and uranographical notes are very full.]

18—. LOHRMANN, W. G., *Karte des Mondes.* Leipzig. [Published by J. A. Barth. A well-executed copper-plate engraving about 3 ft. in diameter. There is also a small engraving by the same author about 15 inches in diameter.]

18—. LECOUTURURIER, M., and CHAPUIS, A., *Carte générale de la lune.* Paris. [Published by Leiber and Faraguet. A rather coarse copper-plate engraving about 15½ inches in diameter.]

1830–59. BERLIN ACADEMY, *Akademische Sternkarten.* Fol. Berlin. [24 equatorial charts—one for each hour of R.A.—30° in extent in declination, by various observers. Contains all stars down to mag. 9, and some smaller ones. Catalogues in a tabular form of the registered stars are appended. The charts are of high value.]

*18—. BRUHNS, C., *Atlas der Astronomie.*

1836. Society for Diffusion of Useful Knowledge, *Six Maps of the Stars on the gnomonic projection, edited by Sir J. W. Lubbock, Bt.* [Epoch 1840. Two editions, large folio and imperial 4to. London. An important and well-executed work, but the value of the maps is impaired by the great distortion of the corners of each. Of the smaller maps a new edition, edited by C. O. Dayman, has appeared.]

1841. Dien, C., *Atlas du Zodiaque.* Large 4to. Paris. [Contains 15 charts on white ground. Full of errors.]

1842. Middleton, J., *Celestial Atlas.* Oblong fol. Norwich. [Contains maps of the stars in duplicate, one set being a fac-simile of the heavens, stars white on black ground; the other, maps ordinary, with constellations and stars engraved in the usual manner and coloured.]

1843. Schwinck, G., *Mappa Cælestis.* Lipsiæ. [Map, on 5 sheets, of stars visible in Central Europe.]

1843. Argelander, F. G. A., *Uranometria Nova.* Oblong demy fol. Berlin. [Contains 17 maps on white ground; boundaries faintly tinted. All stars visible to the naked eye in Europe are inserted, the magnitude being given with great care and precision from original observations. Altogether a highly valuable work.]

1850. Bishop, G., Ecliptic charts for every hour of R. A. [Never completed. Constructed by Hind and others, and published at G. Bishop's expense. Epoch 1825.]

1854. Littrow, J. J. Von, *Atlas des Gestirnten Himmels.* 2nd ed., by C. Von Littrow. 8vo. Stuttgart.

1855. Hind, J. R., *Atlas of Astronomy.* [Contains 18 plates with brief explanations. There are 6 maps of the stars, white on blue ground, of great usefulness for identifying particular stars. A new edition, with additional plates, has appeared.]

1857–61. Bonn Observatory, *Atlas des Nordlichen Gestirnten Himmels.* [For the epoch of 1855·0. Contains 33 (or more) charts on white ground of stars down to mag. 9½: without names or boundaries.]

1862. Chacornac, *Atlas Écliptique.* [To contain (when completed) 72 charts on white ground. No names or boundaries. Stars from mags. 7–13.]

1865. Dien, Ch., *Atlas Céleste.* [Contains 24 charts on white ground, for the epoch of 1860. More than 100,000 stars are given.]

1867. Proctor, R. A., *The Constellation Seasons.* 4to. Lond. [12 charts for different months of the year.]

1870. Proctor, R. A., *A new Star Atlas.* Small fol. London.

1872. Heis, E., *Neuer Himmels Atlas.* Oblong fol. Köln. [Maps for Europe only: with a catalogue of stars in a separate 8vo. volume.]

1874. Behrmann, C., *Atlas des südlichen gestirnten Himmels.* Oblong fol. Leipzig. [Maps for the Southern hemisphere only: with a catalogue of stars in a separate 8vo. volume.]

CHAPTER II.

LIST OF BOOKS RELATING TO, OR BEARING ON, ASTRONOMY[a].

AINSLIE, J., and GALBRAITH, W., *A Treatise on Land Surveying*. 8vo. Edinburgh, 1849.

AIRY, Sir G. B., *Ipswich Lectures*. 8vo. London, 1849. There have been several editions.

ANDRÉ, C., and RAYET, G., *L'Astronomie pratique et les Observatoires en Europe et en Amérique*. Parts i. and ii. Great Britain and the British Colonies. 18mo. Paris, 1874.

ARAGO, D. J. F., *Astronomie Populaire*. 4 vols. 8vo. Paris, 1854–8.

**Popular Astronomy*. Trans. W. H. Smyth and R. Grant. 2 vols. 8vo. London, 1855–8.

Leçons d'Astronomie. 18mo. Bruxelles, 1837.

ARATUS, *Phenomena and Diosemeia*. Translated into English Verse by the Rev. J. Lamb, D.D. 8vo. London, 1847.

ARISTOTELES, *Opera*. Ed. Acad. Reg. Boruss. 4 vols. 4to. Berolini, 1831–6.

**Astronomical Register*. 8vo. London, v. y.

**Astronomische Nachrichten*. 4to. Altona, v. y.

BAILLY, J. S., *Histoire de l'Astronomie Ancienne*. 4to. Paris, 1781.

Histoire de l'Astronomie Moderne. 3 vols. 4to. Paris, 1785.

Traité de l'Astronomie Indienne et Orientale. 4to. Paris, 1787.

BAILY, F., *Astronomical Tables and Formulæ*. 8vo. London, 1827–9.

BARLOW, Rev. J., *Astronomy Simplified for the Use of Schools and Families*. [Q. and A.] 24mo. London, n. d.

*BECKETT, Sir E., *Astronomy without Mathematics*. 6th ed. 8vo. London, 1876. S.P.C.K.

[a] It will be observed that I apply no adjective to this list. I do not call it 'complete,' or 'comprehensive,' or 'select,' or 'useful.' It is simply an enumeration of books which I have, as a matter of fact, consulted or looked at. In the judgment of some persons it may include some worthless books, and may not include some valuable ones. At any rate I shall be very willing to receive suggestions for alterations in it calculated to benefit science. In the case of new books I must be shewn the books themselves. The asterisk (*) denotes books which amateur observers will find useful, and which therefore I must be taken as in some sense recommending.

Beer, W., and Mädler, J. H., *Der Mond.* 4to. Berlin, 1837.

Beima, E. M., *De Annulo Saturni Commentatus est.* 4to. Lugduni Batavorum, 1842.

Bessel, F. W., *Tabulæ Regiomontanæ, reductionum observationum Astronomicarum, 1750–1850 computatæ.* 8vo. Regiomonti, 1830.

Fundamenta Astronomiæ pro anno 1775 deducta ex observationibus viri incomparabilis James Bradley in speculâ Astronomicâ Grenovicensi, &c. Fol. Regiomonti, 1818.

Abhandlungen. Ed. by R. Engelmann. 3 vols. 4to. Leipzig, 1875–6.

Populäre Vorlesungen über wissenschaftliche Gegenstände. 8vo. Hamburg, 1848.

Biot, J. B., *Traité Elémentaire de l'Astronomie Physique.* 3rd ed. 4 vols. Paris, 1844–7.

Résumé de Chronologie Astronomique. 4to. Paris, 1849. [From vol. xxii. of the *Memoires de l'Academie des Sciences.*]

*Boillot, A., *Traité Elémentaire d'Astronomie.* 18mo. Paris, 1866.

Bonnycastle, J., *Introduction to Astronomy.* 8vo. London, 1803.

Bouvier, Hannah M., *Familiar Astronomy.* 8vo. Philadelphia, 1856.

Bradley, Rev. J., D.D., *Miscellaneous Works and Correspondence.* Ed. by Prof. S. P. Rigaud. 4to. Oxford, 1832.

Brady, J., *Clavis Calendaria.* 2nd ed. 2 vols. 8vo. London, 1812.

Brahe, Tycho, *Astronomiæ Instauratæ Progymnasmata.* 2 vols. 4to. Francofurti, 1610.

Breen, H., *Practical Astronomy.* 8vo. London, 1856. [In Orr's *Circle of the Sciences.*]

Brewster, Sir D., *More Worlds than One.* 16mo. Edinburgh, 1854.

Treatise on Optics. 12mo. London, 1853.

Brinkley, Bishop, *Astronomy.* Enlarged by Stubbs and F. Brünnow. 8vo. London, 1874.

British Almanac and Companion. 12mo. London, v. y.

British Association *Reports.* 8vo. London, v. y.

Brocklesby, J., *Elements of Astronomy for Schools and Academies.* 3rd ed. cr. 8vo. New York, 1857.

Bruhns, C., *Handbuch der Logarithmen.* 8vo. Leipzig, 1870.

Brünnow, F., *Lehrbuch der sphärischen Astronomie.* 2nd ed. 8vo. Berlin, 1862.

Spherical Astronomy. Trans. by Main. 8vo. Cambridge, 1860.

Spherical Astronomy. Trans. by Author. 8vo. London, 1865.

*Carl, Ph., *Repertorium der Cometen-Astronomie.* München, 1864.

Chauvenet, W., *A Manual of Spherical and Practical Astronomy.* 2nd ed. 2 vols. 8vo. Philadelphia, 1864.

Christie, J. R., *An Introduction to the Elements of Practical Astronomy.* 8vo. London, 1853.

*Christie, W. H. M., *Astronomy.* Fcp. 8vo. 1875. S.P.C.K.

Comptes Rendus de l'Académie des Sciences. 4to. Paris, v. y.

Comstock, J. L., and Hoblyn, R. D., *Astronomy, with questions on each page.* Fcap. 8vo. London, 1851.

Connaissance des Temps. 8vo. Paris, v. y.

Cooper, E. J., *Cometic Orbits.* 8vo. Dublin, 1852.

Cosmos, Révue des Sciences. 8vo. Paris, v. y.

COSTARD, Rev. G., *History of Astronomy.* 4to. London, 1767. [Scarcely a "History," but interesting as a "Miscellany."]

DELAMBRE, J. B., *Histoire d'Astronomie—Ancienne—du Moyen Age—et Moderne.* 5 vols. 4to. Paris, 1817–21.
Astronomie, théorétique et practique. 3 vols. 4to. Paris, 1814.
Abrégé d'Astronomie ou leçons élémentaires. 8vo. Paris, 1813.
*DELAUNAY, C., *Cours Elémentaire d'Astronomie.* 4th ed. Paris, 1864.
DRAYSON, Capt. A. W., *The Common Sights of the Heavens, and how to see and know them.* 2nd ed. 16mo. London, 1862.
DRECHSTER, A., *Die Sonnen- und Mondfinsternisse in ihrem Verlaufe oder Anleitung wie diese durch Rechnung oder Zeichnung zu ermitteln sind.* 8vo. Dresden, 1858.
DREW, J., *Manual of Astronomy.* 2nd ed. 16mo. London, 1853.
DUBOIS, E., *Cours d'Astronomie.* 2nd ed. 8vo. Paris, 1865.
*DUNKIN, E. *The Midnight Sky.* Imp. 8vo. London, 1869. R.T. Society.

EMERSON, W., *System of Astronomy, containing the Investigation and Demonstration of its Elements.* 8vo. London, 1769.
Encyclopædia Britannica. 4to. Edinburgh, 1874.
ENGELMANN, R., *Ueber die Helligkeitsverhaltnisse der Jupiterstrabenten.* Leipzig, 1871.
ENGLEFIELD, Sir H., *On the Determination of the Orbits of Comets, according to the Methods of Boscovitch and La Place.* 4to. London, 1793.
English Cyclopædia, Arts and Sciences Division. 8 vols. 4to. London, 1859-61.

FAYE, H., *Leçons de Cosmographie.* 2nd ed. 8vo. Paris, 1854.
FERGUSON, J., *Astronomy.* 2nd ed. 4to. London, 1757.
FERGUSON, J., and BREWSTER, D., *Astronomy explained upon Sir I. Newton's Principles.* 2nd ed. 2 vols. 8vo. Edinburgh, 1821.
FLAMMARION, C., *Etudes et Lectures sur l'Astronomie.* 4 vols. 16mo. Paris, 1867.
La Pluralité des Mondes habités; étude ou l'on expose les conditions d'habitabilité des terres celestes. 12mo. Paris, 1864.
L'Atmosphere, description des grands phénomènes de la Nature. 8vo. Paris, 1872.
FLAMSTEED, Rev. J., *Account of his Life,* by F. Baily. 4to. London, 1837.
FREND, W., *Evening Amusements, or the Beauty of the Heavens displayed.* 19 annual vols. 12mo. London, 1804–22.

GALBRAITH, Rev. J., and HAUGHTON, Rev. S., *Manual of Astronomy.* 18mo. London, 1857.
Manual of Optics. 18mo. London, 1857.
GALILEO, G., *Opere.* 16 vols. 8vo. Firenze, 1842–56.
GASSENDI, P., *Omnia Opera.* 6 vols. fol. Florentiæ, 1727.
GAUSS, C. F., *Theoria motvs corporvm coelestivm.* 4to. Hamburgi, 1809.
Theorie der Bewegung der Himmels Körper ... in deutsche übertragen von C. Haase. 4to. Hannover, 1865.
Théorie du Mouvement des corps célestes ... traduction par E. Dubois. 8vo. Paris, 1864.
GODFRAY, H., *Treatise on Astronomy for Colleges and Schools.* 2nd ed. 8vo. London, 1874.

GRANT, R., *History of Physical Astronomy.* 8vo. London, 1852.

GRAVIER, COULVIER-, *Recherches sur les Etoiles Filantes.* 8vo. Paris, 1847.

Greenwich Observations. 4to. London, v. y.

GREGORY, J., *Optica promota, seu abdita Radiorum reflexorum et refractorum mysteria, geometricè enucleata.* Reprint, 4to. London, 1663.

GREGORY, O., *Treatise on Astronomy.* 8vo. London, 1802.

GUILLEMIN, A., *Le Soleil.* 12mo. Paris, 1869.

La Lune. 12mo. Paris, 1866.

Les Comètes. 8vo. Paris, 1875.

Le Ciel, Notions d'Astronomie. 5th ed. 8vo. Paris, 1876. English Edition: *The Heavens.* Trans. Lockyer. 8vo. London, 1865.

**Guy's Elements of Astronomy, and an Abridgement of Keith's New Treatise on the Use of Globes.* 30th ed. fcap. 8vo. Philadelphia, 1853.

HALL, Rev. T. G., *Outlines of Astronomy.* 15th ed. 24mo. London, 1861.

HALLEY, E., *Astronomical Tables, with Precepts both in English and Latin.* 4to. London, 1752.

HARDCASTLE. W., *Familiar Lessons, or a Simple Catechism of Astronomy.* 2nd ed. 24mo. London, n. d.

HASKOLL, *Land and Marine Surveying.* 8vo. London.

HERODOTUS, *Helicarnasseus*, ed. Rev. G. Rawlinson. 4 vols. 8vo. London, 1859–60.

*HERSCHEL, Sir J. F. W., *Outlines of Astronomy.* 12th ed. 8vo. London, 1873.

Results of Astronomical Observations made during the Years 1834–8 *at the Cape of Good Hope.* 4to. London, 1847.

HEVELIUS, J., *Cometographia, totam naturam cometarum ... exhibens.* Fol. Gedani, 1668.

Prodromus Astronomiæ. Fol. Gedani, 1660.

Mercurius in Sole visus. Fol. Gedani, 1662.

Selenographia, sive Lunæ descriptio. Fol. Gedani, 1647.

HILL, J., *Urania, or a compleat View of the Heavens ... in form of a Dictionary.* 4to. London, 1754.

HIND, J. R., **Introduction to Astronomy.* 8vo. London, 1863.

**Solar System.* 12mo. London, 1851.

**The Comets.* 12mo. London, 1852.

The Comet of 1556. 12mo. London, 1857.

History of Astronomy, Library of Useful Knowledge. 8vo. London, 1834.

HOOKE, R., *Attempt to prove the Motion of the Earth from Observation.* 4to. London, 1674.

HUGENIUS, C., ΚΟΣΜΟΘΕΩΡΟΣ, *sive de Terris Cœlestibus, earumque ornatu, conjecturæ.* 2nd ed. 4to. Hagæ Comitum, 1699.

Systema Satvrnivm. Hagæ Comitis, 1659.

Opera Varia. 2 vols. 4to. Lugduni Batavorum, 1724.

HUGGINS, W., *On the Results of Spectrum Analysis applied to the Heavenly Bodies.* A discourse delivered at Nottingham. 16mo. London, 1866.

HUMBOLDT, A. VON, *Cosmos.* Trans. E. C. Otté. 5 vols. 8vo. London, 1849–58.

HUTTON, C., *Mathematical and Philosophical Dictionary.* 2nd ed. 2 vols. 4to. 1815.

JAHN, G. A., *Geschichte der Astronomie vom Anfange des neunzehnten Jahrhunderts bis zu Ende des Jahres* 1842. 2 vols. 8vo. Leipzig, 1844.

JEANS, J. W., *Handbook for finding the Stars.* London, 1848.

*JOHNSTON, A. K., *Atlas of Astronomy*, ed. Hind. 8vo. Edinburgh, 1855.

Physical Atlas. Fol. Edinburgh, 1849.

KAISER, F., *Der Sternenhimmel beschrieben, mit einem Vorwort von J. F. Encke.* 8vo. Berlin, 1850.

KEILL, J., *Introduction to the True Astronomy.* 4th ed. 8vo. London, 1748.

KEITH, T., *Treatise on the Globes*, ed. Rowbotham. 8vo. London, 1844.

KEPLER, J., *Ad Vitellionem Paralipomena, quibus Astronomiæ pars optica traditur.* 4to. Francofurti, 1604.

De Stellâ novâ in Pede Serpentarii. 4to. Pragæ, 1606.

De Motibus Stellæ Martis, ex observationibus Tychonis Brahe. Fol. Pragæ, 1609.

Epitome Astronomiæ Copernicanæ Libri tres priores de doctrinâ sphericâ. 8vo. Lentiis ad Danubium, 1618.

Opera Omnia, ed. Ch. Frisch. 8 vols. 8vo. Frankofurti-a-m, 1857-70.

KERIGAN, T., *A Practical Treatise on the Eclipses of the Sun and Moon ... explaining their calculation by simple and direct Methods.* 8vo. London, 1844.

KIDDLE, H., *A Manual of Astronomy and the use of the Globes for Schools and Academies.* 10th ed. cr. 8vo. New York, 1854.

KITCHENER, *Telescopes.* London, 1825.

KLINKERFUES, W., *Theoretische Astronomie.* 8vo. Braunschweig, 1871.

LA CAILLE, *Elements of Astronomy.* Trans. by J. Robertson. 8vo. London, 1750.

Leçons élémentaires d'Astronomie. New ed. 8vo. Paris, 1761.

LA GRANGE, J. L., *Mécanique Analytique.* 3rd ed., edited by J. Bertrand. 2 vols. 4to. 1853-5.

LALANDE, J. De, *Astronomie.* 4 vols. 4to. Paris, 1792.

Bibliographie Astronomique, avec l'Histoire de l'Astronomie depuis 1781 jusqu'à 1802. 4to. Paris, 1803.

LANGLER, J. R., *The Main Facts of Popular Astronomy and Mathematical Geography.* Fcap. 8vo. London, 1871.

LAPLACE, P. S. De, *Exposition du Système du Monde.* 4th ed. 2 vols. 8vo. Paris, 1813.

Traité de Mécanique Céleste. 5 vols. 4to. Paris, 1798-1827.

Mécanique Céleste ... translated with a Commentary by N. Bowditch. 4 vols. 4to. Boston, U.S., 1829-39.

LARDNER, D., *Handbook of Astronomy.* 2 vols. 12mo. London, 1853; also 2nd ed., ed. E. Dunkin. 1 vol. 12mo. London, 1860.

Museum of Science and Art. 12 vols. 12mo. London, 1854-6.

L'Art de vérifier les Dates des Faites Historiques, des Chartes, des Chroniques, et d'autres anciens Monuments, depuis la Naissance de Notre Seigneur, par le moyen d'une Table Chronologique. 3 vols. fol. Paris, 1783.

L'Institut, Journal Universel des Sciences. Fol. Paris, v. y.

LEWIS, Sir G. C., *An Historical Survey of the Astronomy of the Ancients.* 8vo. Lond. 1862.

LIAIS, E. *Traité d'Astronomie.* 8vo. Paris, 1867.

L'Espace céleste ... description physique de l'Univers. 8vo. Paris.

LINDENAU, VON, *Zeitschrift für Astronomie.* 5 vols. 8vo. Tübingen, 1816-18.

LINNINGTON, R. T., *Compendium of Astronomy ... and Astronomical Dictionary.* 12mo. London, 1830.

Littrow, J. J., *Die Wunder des Himmels.* 4th ed. Stuttgart, 1854.
Lockyer, J. N., *Contributions to Solar Physics.* 8vo. London, 1874.
Long, R., *Astronomy.* 2 vols. 4to. Cambridge, 1742.
Loomis, E., *History of Astronomy, especially in the United States.* 12mo. New York, 1856.
**Practical Astronomy.* 8vo. New York, 1855.
Treatise on Astronomy. 8vo. New York, 1866.
Treatise on Meteorology. 8vo. New York, 1868.
Lubienitz, S. De, *Theatrum Cometicum.* 2 vols. fol. Amsterdam, 1668.
Lucretius, *De Rerum Naturâ*, trans. Watson, vol. 26, Bohn's *Class. Library.* 8vo. London, 1851.

M'Intire, J., M.D., *A New Treatise on Astronomy and the Use of the Globes.* Cr. 8vo. New York, 1860.
*Mädler, J. H., *Populäre Astronomie.* 5th ed. 8vo. Berlin, 1861.
**Kurzer Abriss der Astronomie.* 8vo. Essen, 1863.
Magnaghi, G. B., *Gli strumenti a Riflessione per misurare angoli.* 8vo. Milan, 1875.
Mailla, J. A. M. De, *Histoire Générale de la Chine.* 4to. Paris, 1776 *et seq.*
Mailly, E., *Tableau d'Astronomie dans l'Hemisphere austral et dans l'Inde.* 8vo. Bruxelles, 1872.
Main, Rev. R., *Practical and Spherical Astronomy for the use chiefly of Students in the Universities.* 8vo. Cambridge, 1863.
Rudimentary Treatise on Astronomy, Weale's Series, vol. 96. 12mo. London, 1852.
Manilius, *Astronomicon, in usum Delphinum.* Ed. by Pingré. 2 vols. 8vo. Paris.
In English Verse. 8vo. London, 1697.
Mann, R. J., M.D., F.R.A.S., *The Heavens, a Guide to Astronomical Science.* 24mo. London, n. d.
Mattison, H., A.M., *A High School Astronomy, in which the Descriptive, Physical, and Practical are combined.* Cr. 8vo. New York, 1854.
**A Primary Astronomy for Schools and Families.* [Q. and A.] Cr. 8vo. New York, 1853.
Milne, D., *Essay on Comets.* 4to. Edinburgh, 1828.
Milner, Rev. T., *Gallery of Nature.* 2nd ed. 8vo. London, 1859.
Mitchell, O. M. *The Orbs of Heaven.* 8vo. London, 1853.
Montemont, A., *Lettres sur l'Astronomie.* 4 vols. 24mo. Paris, 1823. [Vol. i. contains a Vocabulary.]
Montucla, J. F., *Histoire des Mathématiques.* Ed. Lalande. 4 vols. 8vo. Paris, 1799–1802.
Moon, The. Fcap. 8vo. London, n. d. (S.P.C.K.)
Morgan, A. De, *The Book of Almanacs.* Oblong 8vo. London, 1851.
Moseley, Rev. H:, *Lectures on Astronomy.* 12mo. London, 1850.
Astro-Theology. 3rd ed. fcap. 8vo. London, 1860.

Nagy, K., *Die Sonne und die Astronomie.* Imp. 8vo. Leipzig, 1866.
Narrien, J., *Origin and Progress of Astronomy.* 8vo. London, 1833.
**Nautical Almanac.* 8vo. London, v. y.
Nasmyth, J., and Carpenter, J., *The Moon.* 4to. London, 1874.
Nichol, J. P., *Architecture of the Heavens.* 9th ed. 8vo. London, 1851.
Cyclopædia of the Physical Sciences. 2nd ed. 8vo. London, 1860.

*NORTON, W. A., *An Elementary Treatise on Astronomy ... with Tables.* 3rd ed. 8vo. New York, 1852.

NÜRNBERGER, J. E., *Populäres astronomisches Hand-Wörterbuch*, vol. i. A–K. 8vo. Kempten, 1846.

OLMSTED, D., *Mechanism of the Heavens.* 8vo. Edinburgh.

PARKER, R. G., *Astronomy, with Questions for Examination.* [In Parker's Educational Course.] Fcp. 8vo. London, 1855.

PEARSON, Rev. W., *Introduction to Practical Astronomy.* 2 vols. 4to. London, 1824–9.

PENROSE, F. C., *A Method of Predicting by graphical Construction Occultations of Stars.* Fol. London, 1869.

PETAVIUS, D., *Uranologion: Systema variorum auctorum de Sphærâ.* Folio. Lutet. 1630.

PETIT, F., *Traité d'Astronomie pour les gens du Monde.* 2 vols. 16mo. Paris, 1866.

Philosophical Journal. 8vo. Edinburgh, v. y.

Philosophical Magazine. 8vo. London, v. y.

Pictures of the Heavens. 2nd ed. fcap. 8vo. London, 1859.

PINGRÉ, A., *Cométographie; ou Traité historique et théoretique des Comètes.* 2 vols. 4to. Paris, 1783.

PLUTARCHUS, *Opera.* Ed. Reiske. 12 vols. Lipsiæ, 1778.

PONTÉCOULANT, G. De, *Théorie analytique du système du Monde.* 2nd ed. 3 vols. Paris, 1856.

Traité élémentaire de physique Céleste, ou Précis d'Astronomie théorétique et pratique. 8vo. Paris, 1840.

PROCTOR, R. A., *Saturn and its System.* 8vo. London, 1865.

The Sun. 3rd ed. 8vo. London, 1876.

The Orbs around us. 8vo. London, 1872.

The Moon. 8vo. London, 1873.

Elementary Astronomy. 3rd ed. Fcp. 8vo. London, 1873.

PTOLEMÆUS CLAUDIUS, *Almagestum.* Fol. Colon., 1515.

QUETELET, A., *Eléments d'Astronomie.* 12mo. Paris, 1847.

REES, A., *Cyclopædia of Arts, Sciences, and Literature.* 45 vols. 4to. London, 1819.

RICCIOLI, J. B., *Almagestum Novum.* 2 vols. fol. Bononiæ, 1653.

RIOS, J. DE MENDOZA, *A complete Collection of Tables for Navigation and Nautical Astronomy.* 4to. London, 1803.

ROSCOE, H. E., *Spectrum Analysis, Six Lectures.* 2nd ed. 8vo. London, 1870.

ROYAL ASTRONOMICAL SOCIETY, *Memoirs.* 4to. London, v. y.

**Monthly Notices.* 8vo. London, v. y.

ROYAL IRISH ACADEMY, *Transactions.* 8vo. Dublin, v. y.

ROYAL SOCIETY, *Philosophical Transactions.* 4to. London, v. y.

ROYAL SOCIETY OF EDINBURGH, *Transactions.* 4to. Edinburgh, v. y.

RYAN, J., *The New American Grammar of the Elements of Astronomy.* Fcap. 8vo. New York, 1839.

SANTINI, G., *Elementi di Astronomia.* 2 vols. 4to. Padova, 1819–22.

SAWITSCH, A., *Abriss der practischen Astronomie ... aus dem Russischen übersetzt von Dr. W. C. Goetze.* 2 vols. 8vo. Hamburg, 1850.

Scheiner, C., *Rosa Vrsina, sive Sol ex admirando Facvlarvm & Macvlarvm svarvm phenomeno varivs, &c.* Fol. Bracciani, 1629.

Schellen, H., *Spectrum Analysis.* Translated by J. and C. Lassell, and edited by W. Huggins. 8vo. London, 1872.

Schiaparelli, J. V., *Entwurf einer Astronomischen Theorie der Sternschnuppen ... aus dem Italienischen übersetzt und herausgegeben von G. Von Boguslawski.* 8vo. Stettin, 1871.

Schlegel, G., *Uranographie chinoise, ou preuves directes que l'Astronomie primitive est originaire de la Chine.* 2 vols. 8vo. La Haye, 1875.

Schmidt, J. F. J., *Das Zodiacallicht.* 8vo. 1856.

Resultate aus zehnjährigen Beobachtungen über Sternschnuppen. 1852.

Resultate aus elfährigen Beobachtungen der Sonnenflecken. 1857.

Schröter, J. J., *Selenotopographische Fragmente zur genauern Kenntniss der Mondfläche.* 2 vols. 4to. Lilienthal, 1791–1802.

Schubert, F. T., *Traité d'Astronomie Théorétique.* 3 vols. 4to. St. Pétersbourg, 1822.

Secchi, A., *Quadro Fisico del Sistema Solare.* 16mo. Roma, 1859.

Seidel, L., *Untersuchungen über die gegenseitigen Helligkeiten der Fixsterne erster Grösse, &c.* Munich, 1852.

Shadwell, Capt. C. F. A., *Notes on the Management of Chronometers.* 8vo. London, 1861.

Simms, W., *The Achromatic Telescope.* 8vo. London, 1852.

Small, R., *Account of the Astronomical Discoveries of Kepler.* 8vo. London, 1804.

Smith, Robert, *A complete System of Opticks.* 2 vols. 4to. Cambridge, 1738.

Smyth, C. P., *Teneriffe; an Astronomer's Experiment.* 8vo. London, 1858.

*Smyth, W. H., *Cycle of Celestial Objects.* 2 vols. 8vo. London, 1844.

Speculum Hartwellianum. 4to. London, 1860.

Sidereal Chromatics. 8vo. London, 1864.

Snooke, W. D., *Brief Astronomical Tables for the expeditious Calculation of Eclipses.* 8vo. London, 1852.

Somerville, Mary, *Connexion of the Physical Sciences.* 9th ed. 8vo. London.

Mechanism of the Heavens. 8vo. London.

Struve, F. G. W., *Etudes d'Astronomie Stellaire.* 8vo. St. Petersburg, 1847.

Tacchini, P., *Il passaggio di Venere sul Sole dell'* 8–9 *Dicembre* 1874. 4to. Palermo, 1875.

Tate, T., *Astronomy and the use of the Globes.* [In Gleig's School Series.] 24mo. London, 1858.

Theophrastus, *Opera Omnia.* Ed. Heinsius. Fol. Lugduni Batavorum, 1613.

Thomson, D. P., *Introduction to Meteorology.* 8vo. Edinburgh, 1849.

Tides, The. Fcap. 8vo. London, 1857. (S.P.C.K.)

*Tomlinson, Rev. L., *Recreations in Astronomy.* 5th ed. 16mo. London, 1858.

Ursinus, G. F., *Logarithmi VI Decimalium ... quibus additi sunt varii Logarithmi et numeri sæpius in Mathesi adhibiti.* 8vo. Hafniæ, 1827.

Vince, Rev. S., *Complete System of Astronomy.* 3 vols. 4to. Cambridge, 1797–1808.

Watson, J. C., *Theoretical Astronomy ... with auxiliary Tables.* 8vo. Philadelphia, 1868.

*WEBB, Rev. T. W., *Celestial Objects for common Telescopes.* 3rd ed. 16mo. London, 1873.

WHEWELL, Rev. W., *Astronomy and general Physics considered with reference to Natural Theology.* 8vo. London, 1833. [Vol. iii. of the "Bridgewater Treatises."]

WHITING, T., *A Comprehensive System of Astronomy, both Theoretic and Practical.* 4to. London, 1828. [Contains a very full vocabulary of definitions.]

WILLARD, E., *Astronography, or Astronomical Geography.* [In Cassell's Educational Course.] 8vo. London, n. d.

WILLIAMS, W. M., *The Fuel of the Sun.* 8vo. London, 1870.

WILSON, Rev. T., *Catechism of Astronomy.* Fcap. 8vo. London, n. d.

WING, V., *Astronomia Britannica.* Fol. London, 1669.

WOLF, R., *Taschenbuch für Mathematik, Physik, Geodäsie und Astronomie.* 4th ed. 16mo. Zürich, 1869.

Handbuch der Mathematik ... und Astronomie. 2 vols. 8vo. Zürich, 1872.

Wonders of the Heavens displayed in 20 Lectures. 12mo. London, 1821.

WRIGHT, T., *An original Theory or new Hypothesis of the Universe.* 4to. London, 1750.

ZACH, F. Von, *Monatliche Correspondenz zur beförderung der Erd- und Himmels-Kunde.* 26 vols. 8vo. Gotha, 1800–13. With a *Register* or general Index by J. G. Galle. 8vo. Gotha, 1850.

Correspondence Astronomique. 14 vols. 8vo. Gênes, 1818–26.

ZÖLLNER, J. C. F., *Ueber die Natur der Cometen Beitrage zur Geschichte und Theorie der Erkenntniss.* 8vo. Leipzig, 1872.

BOOK XII.

ASTRONOMICAL TABLES.

THE elements of the planets discovered since 1873 being, at the time of going to press, either unknown or determined only approximately, I have been obliged to be content with giving only a few details connected with these planets. Many are still in want of names; it is becoming increasingly difficult to find names for these bodies.

I. FOR CONVERTING INTERVALS OF MEAN SOLAR TIME

HOURS.		MINUTES.				SECONDS.			
Hours of Mean Time.	Equivalents in Sidereal Time.	Minutes of Mean Time.	Equivalents in Sidereal Time.	Minutes of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time.
	h. m. s.		m. s.		m. s.		s.		s.
1	1 0 9·8565	1	1 0·1643	31	31 5·0925	1	1·0027	31	31·0849
2	2 0 19·7130	2	2 0·3286	32	32 5·2568	2	2·0055	32	32·0876
3	3 0 29·5694	3	3 0·4928	33	33 5·4211	3	3·0082	33	33·0904
4	4 0 39·4259	4	4 0·6571	34	34 5·5853	4	4·0110	[illegible]	34·0931
5	5 0 49·2824	5	5 0·8214	35	35 5·7496	5	5·0137	35	35·0958
6	6 0 59·1388	6	6 0·9857	36	36 5·9139	6	6·0164	36	36·0986
7	7 1 8·9953	7	7 1·1499	37	37 6·0782	7	7·0192	37	37·1013
8	8 1 18·8518	8	8 1·3142	38	38 6·2424	8	8·0219	38	38·1040
9	9 1 28·7083	9	9 1·4785	39	39 6·4067	[illegible]	9·0246	39	39·1068
10	10 1 38·5647	10	10 1·6428	40	40 6·5710	10	10·0274	40	40·1095
11	11 1 48·4212	11	11 1·8070	41	41 6·7353	11	11·0301	41	41·1123
12	12 1 58·2777	12	12 1·9713	42	42 6·8995	12	12·0329	42	42·1150
13	13 2 8·1342	13	13 2·1356	43	43 7·0638	13	13·0356	43	43·1177
14	14 2 17·9906	14	14 2·2998	44	44 7·2281	14	14·0383	44	44·1205
15	15 2 27·8471	15	15 2·4641	45	45 7·3924	15	15·0411	45	45·1232
16	16 2 37·7036	16	16 2·6284	46	46 7·5566	16	16·0438	46	46·1259
17	17 2 47·5600	17	17 2·7927	47	47 7·7209	17	17·0465	47	47·1287
18	18 2 57·4165	18	18 2·9569	48	48 7·8852	18	18·0493	48	48·1314
19	19 3 7·2730	19	19 3·1212	[illegible]	49 8·0495	19	19·0520	49	49·1342
20	20 3 17·1295	20	20 3·2855	50	50 8·2137	[illegible]	20·0548	50	50·1369
21	21 3 26·9859	21	21 3·4498	51	51 8·3780	21	21·0575	51	51·1396
22	22 3 36·8424	22	22 3·6140	52	52 8·5423	22	22·0602	52	52·1424
23	23 3 46·6989	23	23 3·7783	53	53 8·7066	23	23·0630	53	53·1451
24	24 3 56·5554	24	24 3·9426	54	54 8·8708	24	24·0657	54	54·1479
		25	25 4·1069	55	55 9·0351	25	25·0685	55	55·1506
		26	26 4·2711	56	56 9·1994	26	26·0712	56	56·1533
		27	27 4·4354	57	57 9·3637	27	27·0739	57	57·1561
		28	28 4·5997	58	58 9·5279	28	28·0767	58	58·1588
		29	29 4·7640	59	59 9·6922	29	29·0794	59	59·1615
		30	30 4·9282	60	60 9·8565	30	30·0821	60	60·1643

INTO EQUIVALENT INTERVALS OF SIDEREAL TIME.

FRACTIONS OF A SECOND.

Seconds of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time.
	s.		s.		s.
0·01	0·01003	0·34	0·34093	0·67	0·67183
0·02	0·02006	0·35	0·35096	0·68	0·68186
0·03	0·03008	0·36	0·36099	0·69	0·69189
0·04	0·04011	0·37	0·37101	0·70	0·70192
0·05	0·05014	0·38	0·38104	0·71	0·71194
0·06	0·06016	0·39	0·39107	0·72	0·72197
0·07	0·07019	0·40	0·40110	0·73	0·73200
0·08	0·08022	0·41	0·41112	0·74	0·74203
0·09	0·09025	0·42	0·42115	0·75	0·75205
0·10	0·10027	0·43	0·43118	0·76	0·76208
0·11	0·11030	0·44	0·44120	0·77	0·77211
0·12	0·12033	0·45	0·45123	0·78	0·78214
0·13	0·13036	0·46	0·46126	0·79	0·79216
0·14	0·14038	0·47	0·47129	0·80	0·80219
0·15	0·15041	0·48	0·48131	0·81	0·81222
0·16	0·16044	0·49	0·49134	0·82	0·82225
0·17	0·17047	0·50	0·50137	0·83	0·83227
0·18	0·18049	0·51	0·51140	0·84	0·84230
0·19	0·19052	0·52	0·52142	0·85	0·85233
0·20	0·20055	0·53	0·53145	0·86	0·86235
0·21	0·21057	0·54	0·54148	0·87	0·87238
0·22	0·22060	0·55	0·55151	0·88	0·88241
0·23	0·23063	0·56	0·56153	0·89	0·89244
0·24	0·24066	0·57	0·57156	0·90	0·90246
0·25	0·25068	0·58	0·58159	0·91	0·91249
0·26	0·26071	0·59	0·59162	0·92	0·92252
0·27	0·27074	0·60	0·60164	0·93	0·93255
0·28	0·28077	0·61	0·61167	0·94	0·94257
0·29	0·29079	0·62	0·62170	0·95	0·95260
0·30	0·30082	0·63	0·63173	0·96	0·96263
0·31	0·31085	0·64	0·64175	0·97	0·97266
0·32	0·32088	0·65	0·65178	0·98	0·98268
0·33	0·33090	0·66	0·66181	0·99	0·99271

This Table is useful for the conversion of Mean Solar into Sidereal Time.

Sidereal Time *required* = Sidereal Time at the *preceding* Mean Noon + the Equivalent to the *given* Mean Time.

Example.—To convert $2^h\ 22^m\ 25{\cdot}62^s$ Mean Time at Greenwich, Jan. 7, 1870, into Sidereal Time.

		h.	m.	s.
Sidereal Time at the *preceding* Mean Noon, viz. Jan. 7 ..		19	7	23·78
For Mean Intervals. $2^h\ 0^m\ 0^s$	The Table gives the Equivalent Sidereal Intervals.	2	0	19·713
22 0			22	3·614
25				25·069
0·62				0·622
The Sum is the Sidereal Time required ..		21	30	12·80

II. FOR CONVERTING INTERVALS OF SIDEREAL TIME

HOURS.		MINUTES.				SECONDS.			
Hours of Sidereal Time.	Equivalents in Mean Time.	Minutes of Sidereal Time.	Equivalents in Mean Time.	Minutes of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.
	h. m. s.		m. s.		m. s.		s.		s.
1	0 59 50·1704	1	0 59·8362	31	30 54·9214	1	0·9973	31	30·9154
2	1 59 40·3409	2	1 59·6723	32	31 54·7576	2	1·9945	32	31·9126
3	2 59 30·5113	3	2 59·5085	33	32 54·5937	3	2·9918	33	32·9099
4	3 59 20·6818	4	3 59·3447	34	33 54·4299	4	3·9891	34	33·9072
5	4 59 10·8522	5	4 59·1809	35	34 54·2661	5	4·9864	35	34·9045
6	5 59 1·0226	6	5 59·0170	36	35 54·1023	6	5·9836	36	35·9017
7	6 58 51·1931	7	6 58·8532	37	36 53·9384	7	6·9809	37	36·8990
8	7 58 41·3635	8	7 58·6894	38	37 53·7746	8	7·9782	38	37·8963
9	8 58 31·5340	9	8 58·5256	39	38 53·6108	9	8·9754	39	38·8935
10	9 58 21·7044	10	9 58·3617	40	39 53·4470	10	9·9727	40	39·8908
11	10 58 11·8748	11	10 58·1979	41	40 53·2831	11	10·9700	41	40·8881
12	11 58 2·0453	12	11 58·0341	42	41 53·1193	12	11·9672	42	41·8853
13	12 57 52·2157	13	12 57·8703	43	42 52·9555	13	12·9645	43	42·8826
14	13 57 42·3862	14	13 57·7064	44	43 52·7917	14	13·9618	44	43·8799
15	14 57 32·5566	15	14 57·5426	45	44 52·6278	15	14·9591	45	44·8772
16	15 57 22·7270	16	15 57·3788	46	45 52·4640	16	15·9563	46	45·8744
17	16 57 12·8975	17	16 57·2150	47	46 52·3002	17	16·9536	47	46·8717
18	17 57 3·0679	18	17 57·0511	48	47 52·1364	18	17·9509	48	47·8690
19	18 56 53·2384	19	18 56·8873	49	48 51·9725	19	18·9481	49	48·8662
20	19 56 43·4088	20	19 56·7235	50	49 51·8087	20	19·9454	50	49·8635
21	20 56 33·5792	21	20 56·5597	51	50 51·6449	21	20·9427	51	50·8608
22	21 56 23·7497	22	21 56·3958	52	51 51·4810	22	21·9399	52	51·8580
23	22 56 13·9201	23	22 56·2320	53	52 51·3172	23	22·9372	53	52·8553
24	23 56 4·0906	24	23 56·0682	54	53 51·1534	24	23·9345	54	53·8526
		25	24 55·9044	55	54 50·9896	25	24·9318	55	54·8499
		26	25 55·7405	56	55 50·8257	26	25·9290	56	55·8471
		27	26 55·5767	57	56 50·6619	27	26·9263	57	56·8444
		28	27 55·4129	58	57 50·4981	28	27·9236	58	578417
		29	28 55·2490	59	58 50·3343	29	28·9208	59	58·8389
		30	29 55·0852	60	59 50·1704	30	29·9181	60	59·8362

INTO EQUIVALENT INTERVALS OF MEAN SOLAR TIME.

FRACTIONS OF A SECOND.

Seconds of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.
	s.		s.		s.
0·01	0·00997	0·34	0·33907	0·67	0·66817
0·02	0·01995	0·35	0·34904	0·68	0·67814
0·03	0·02992	0·36	0·35902	0·69	0·68812
0·04	0·03989	0·37	0·36899	0·70	0·69809
0·05	0·04986	0·38	0·37896	0·71	0·70806
0·06	0·05984	0·39	0·38894	0·72	0·71803
0·07	0·06981	0·40	0·39891	0·73	0·72801
0·08	0·07978	0·41	0·40888	0·74	0·73798
0·09	0·08975	0·42	0·41885	0·75	0·74795
0·10	0·09973	0·43	0·42883	0·76	0·75793
0·11	0·10970	0·44	0·43880	0·77	0·76790
0·12	0·11967	0·45	0·44877	0·78	0·77787
0·13	0·12965	0·46	0·45874	0·79	0·78784
0·14	0·13962	0·47	0·46872	0·80	0·79782
0·15	0·14959	0·48	0·47869	0·81	0·80779
0·16	0·15956	0·49	0·48866	0·82	0·81776
0·17	0·16954	0·50	0·49864	0·83	0·82773
0·18	0·17951	0·51	0·50861	0·84	0·83771
0·19	0·18948	0·52	0·51858	0·85	0·84768
0·20	0·19945	0·53	0·52855	0·86	0·85765
0·21	0·20943	0·54	0·53853	0·87	0·86762
0·22	0·21940	0·55	0·54850	0·88	0·87760
0·23	0·22937	0·56	0·55847	0·89	0·88757
0·24	0·23934	0·57	0·56844	0·90	0·89754
0·25	0·24932	0·58	0·57842	0·91	0·90752
0·26	0·25929	0·59	0·58839	0·92	0·91749
0·27	0·26926	0·60	0·59836	0·93	0·92746
0·28	0·27924	0·61	0·60833	0·94	0·93743
0·29	0·28921	0·62	0·61831	0·95	0·94741
0·30	0·29918	0·63	0·62828	0·96	0·95738
0·31	0·30915	0·64	0·63825	0·97	0·96735
0·32	0·31913	0·65	0·64823	0·98	0·97732
0·33	0·32910	0·66	0·65820	0·99	0·98730

This Table is useful for the conversion of Sidereal into Mean Solar Time.

Mean Solar Time *required* = Mean Time at the *preceding* Sidereal Noon + the Equivalent to the *given* Sidereal Time.

Example.—To convert 21h 30m 12·80s Sidereal Time at Greenwich, Jan. 7, 1870, into Mean Time.

		h. m. s.
Mean Time at the *preceding* Sidereal Noon, viz. Jan. 6 ..		4 55 44·19
For Sidereal Intervals	21h 0m 0s	The Table gives the Equivalent Mean Intervals: 20 56 33·579
	30 0	29 55·085
	12	11·967
	0·80	0·798
The Sum is the Mean Time required, Jan. 7 ..		2 22 25·62

III.

FOR REDUCING LONGITUDE TO TIME.

°	H.	M.	°	H.	M.	Degrees.	Hours.	Minutes.
′	M.	S.	′	M.	S.			
″	S.	T.	″	S.	T.			
1	0	4	31	2	4	70	4	40
2	0	8	32	2	8	80	5	20
3	0	12	33	2	12	90	6	0
4	0	16	34	2	16	100	6	40
5	0	20	35	2	20	110	7	20
6	0	24	36	2	24	120	8	0
7	0	28	37	2	28	130	8	40
8	0	32	38	2	32	140	9	20
9	0	36	39	2	36	150	10	0
10	0	40	40	2	40	160	10	40
11	0	44	41	2	44	170	11	20
12	0	48	42	2	48	180	12	0
13	0	52	43	2	52	190	12	40
14	0	56	44	2	56	200	13	20
15	1	0	45	3	0	210	14	0
16	1	4	46	3	4	220	14	40
17	1	8	47	3	8	230	15	20
18	1	12	48	3	12	240	16	0
19	1	16	49	3	16	250	16	40
20	1	20	50	3	20	260	17	20
21	1	24	51	3	24	270	18	0
22	1	28	52	3	28	280	18	40
23	1	32	53	3	32	290	19	20
24	1	36	54	3	36	300	20	0
25	1	40	55	3	40	310	20	40
26	1	44	56	3	44	320	21	20
27	1	48	57	3	48	330	22	0
28	1	52	58	3	52	340	22	40
29	1	56	59	3	56	350	23	20
30	2	0	60	4	0	360	24	0

IV.

FOR REDUCING TIME TO LONGITUDE.

Hours.	Degrees.	M.	°	′	M.	°	′
		S.	′	″	S.	′	″
		T.	″	‴	T.	″	‴
1	15	1	0	15	31	7	45
2	30	2	0	30	32	8	0
3	45	3	0	45	33	8	15
4	60	4	1	0	34	8	30
5	75	5	1	15	35	8	45
6	90	6	1	30	36	9	0
7	105	7	1	45	37	9	15
8	120	8	2	0	38	9	30
9	135	9	2	15	39	9	45
10	150	10	2	30	40	10	0
11	165	11	2	45	41	10	15
12	180	12	3	0	42	10	30
13	195	13	3	15	43	10	45
14	210	14	3	30	44	11	0
15	225	15	3	45	45	11	15
16	240	16	4	0	46	11	30
17	255	17	4	15	47	11	45
18	270	18	4	30	48	12	0
19	285	19	4	45	49	12	15
20	300	20	5	0	50	12	30
21	315	21	5	15	51	12	45
22	330	22	5	30	52	13	0
23	345	23	5	45	53	13	15
24	360	24	6	0	54	13	30
		25	6	15	55	13	45
		26	6	30	56	14	0
		27	6	45	57	14	15
		28	7	0	58	14	30
		29	7	15	59	14	45
		30	7	30	60	15	0

The first of the two preceding tables is used for reducing longitude to time, at the rate of 15° to 1^{h}.

The degrees, minutes, or seconds are given in the odd columns, and the corresponding time in the even columns. When the 1st column is reckoned degrees, the 2nd is hours and minutes of time; and when the 1st is minutes of arc, the 2nd is minutes and seconds of time; and so on.

EXAMPLE:—Convert $161^{\circ}\ 5'\ 20''$ of longitude into time.

		h.	m.	s.
160°	=	10	40	0
1°	=		4	0
$5'$	=			20
$20''$	=			1·3
Required time		10	44	21·3

The 2nd table is the converse of the 1st. The time is given in the odd, and the longitude in the even columns. The corresponding denominations of time and space are to be understood as in the preceding table.

EXAMPLE:—Convert $5^{h}\ 8^{m}\ 12^{s}$ into longitude.

		°	′	″
5^{h}	=	75	0	0
8^{m}	=	2	0	0
12^{s}	=		3	0
Required longitude		77	3	0

Three meridians are commonly employed by astronomers from which to reckon time: Berlin, Greenwich, and Washington.

To convert Berlin into Greenwich Time. SUBTRACT $0^{h}\ 53^{m}\ 35{\cdot}5^{s}$, or the decimal of a day, 0·0372164.

To convert Greenwich into Berlin Time. ADD the preceding quantities.

To convert Berlin into Washington Time. SUBTRACT $6^{h}\ 1^{m}\ 47{\cdot}5^{s}$, or the decimal 0·2512441.

To convert Washington into Berlin Time. ADD the preceding quantities.

To convert Greenwich into Washington Time. SUBTRACT $5^{h}\ 8^{m}\ 12{\cdot}0^{s}$, or the decimal 0·2140277.

To convert Washington into Greenwich Time. ADD the preceding quantities.

V. DAYS EXPRESSED AS DECIMALS OF A YEAR.

		1	2	3	4	5	6	7	8	9
		·0027	·0054	·0082	·0109	·0137	·0164	·0191	·0219	·0246
10	·0274	·0301	·0328	·0356	·0383	·0411	·0438	·0465	·0493	·0520
20	·0548	·0575	·0602	·0639	·0657	·0685	·0712	·0739	·0767	·0794
30	·0822	·0849	·0876	·0904	·0931	·0959	·0986	·1013	·1041	·1068
40	·1096	·1123	·1150	·1178	·1205	·1233	·1260	·1287	·1315	·1342
50	·1370	·1397	·1424	·1452	·1479	·1506	·1534	·1561	·1589	·1616
60	·1644	·1671	·1698	·1726	·1753	·1781	·1808	·1835	·1863	·1890
70	·1918	·1945	·1972	·2000	·2027	·2054	·2082	·2109	·2137	·2164
80	·2192	·2219	·2246	·2274	·2301	·2329	·2356	·2383	·2411	2438
90	·2466	·2493	·2520	·2548	·2575	·2603	·2630	·2657	·2687	·2712
100	·2740	·2767	·2794	·2822	·2849	·2876	·2904	·2931	·2959	·2986
110	·3013	·3041	·3068	·3096	·3123	·3150	·3178	·3205	·3233	3260
120	·3287	·3315	·3342	·3370	·3397	·3424	·3452	·3479	·3507	·3534
130	·3561	·3589	·3616	·3644	·3671	·3698	·3726	·3753	·3781	·3808
140	·3835	3863	·3890	·3918	·3945	·3972	·4000	·4027	·4054	·4082
150	·4109	·4137	·4164	·4192	·4219	·4246	·4274	·4301	·4329	·4356
160	·4383	·4411	·4438	·4466	·4493	·4520	·4548	·4575	·4603	·4630
170	·4657	·4685	·4712	·4740	·4767	·4794	·4822	·4849	·4877	·4904
180	·4931	·4959	·4986	·5013	5041	·5068	·5096	·5123	·5150	·5178
190	·5205	·5233	·5260	·5287	·5315	·5342	·5370	·5397	5424	·5452
200	·5479	·5507	·5534	·5561	·5589	·5616	·5644	·5671	5698	·5726
210	·5753	·5781	·5808	·5835	·5863	·5890	·5918	·5945	·5972	·6000
220	·6027	·6055	·6082	·6109	·6137	·6164	6192	·6219	6246	·6274
230	·6301	·6329	·6356	·6383	·6411	·6438	6466	·6493	·6520	·6548
240	·6575	·6603	·6630	·6657	·6685	·6712	6740	·6767	·6794	·6822
250	·6850	·6877	·6904	6931	·6959	·6986	·7013	·7041	7068	·7096
260	·7123	·7151	·7178	·7205	·7232	·7260	·7287	7315	·7342	7370
270	·7397	·7424	·7452	7479	·7507	·7534	·7561	·7589	7616	·7644
280	·7671	7698	7726	·7753	·7781	·7808	·7835	7863	·7890	·7918
290	·7945	·7972	8000	·8027	8055	·8082	8109	·8137	·8164	·8192
300	·8219	·8246	·8274	·8301	·8328	·8356	8383	·8411	·8438	·8466
310	·8493	·8520	·8548	·8575	·8603	·8630	·8657	8685	·8712	·8740
320	·8767	·8794	·8822	·8849	·8877	·8904	·8931	·8959	·8986	·9013
330	·9041	·9068	9096	·9123	·9150	·9178	·9205	9233	·9260	·9287
340	·9315	·9342	·9370	·9397	·9424	·9452	·9479	·9507	·9534	·9561
350	·9589	·9616	·9644	·9671	·9698	·9726	·9753	·9781	·9808	·9835
360	·9863	·9890	·9918	·9945	·9972	1·0000				

Example 1.—What decimal of a year is 227 days? *Ans.* 0·6219.
Example 2.—What day of the year corresponds to the decimal 0·1123? *Ans.* The 41st, = Feb. 10.

VI.

HOURS EXPRESSED AS DECIMAL PARTS OF A DAY.

Hours.	Decimal.
1	·0416
2	·0833
3	·1250
4	·1666
5	·2083
6	·2500
7	·2916
8	·3333
9	·3750
10	·4166
11	·4583
12	·5000
13	·5416
14	·5833
15	·6249
16	·6666
17	·7083
18	·7500
19	·7916
20	·8333
21	·8749
22	·9166
23	·9583
24	1·0000

VII.

MINUTES EXPRESSED AS DECIMAL PARTS OF A DAY.

Minutes.	Decimal.	Minutes.	Decimal.
1	·0006	31	·0215
2	·0013	32	·0222
3	·0020	33	·0229
4	·0027	34	·0236
5	·0034	35	·0243
6	·0041	36	·0250
7	·0048	37	·0256
8	·0055	38	·0263
9	·0062	39	·0270
10	·0069	40	·0277
11	·0076	41	·0284
12	·0083	42	·0291
13	·0090	43	·0298
14	·0097	44	·0305
15	·0104	45	·0312
16	·0111	46	·0319
17	·0118	47	·0326
18	·0125	48	·0333
19	·0131	49	·0340
20	·0138	50	·0347
21	·0145	51	·0354
22	·0152	52	·0361
23	·0159	53	·0368
24	·0166	54	·0375
25	·0173	55	·0381
26	·0180	56	·0388
27	·0187	57	·0395
28	·0194	58	·0402
29	·0201	59	·0409
30	·0208	60	·0416

VIII. DAYS OF THE MONTHS EXPRESSED AS DAYS OF THE YEAR.

	5	10	15	20	25	30
January	5	10	15	20	25	30
February	35	41	46	51	56	
March	64	69	74	79	84	89
April	95	100	105	110	115	120
May	125	130	135	140	145	150
June	156	161	166	171	176	181
July	186	191	196	201	206	211
August	217	222	227	232	237	242
September	248	253	258	263	268	273
October	278	283	288	293	298	303
November	309	314	319	324	329	334
December	339	344	349	354	359	364

N.B. If the year is leap-year, an extra day must be allowed for from March 1.

The following are some illustrations of the many practical applications of the 4 preceding tables.

Example I.

The epochs of certain astronomical observations, such as the measurements of double stars, are expressed in years and decimals of a year. Suppose that an observer at Oxford, on April 15, 1864, measured the distance of the component stars of ξ Libræ, and found it to amount to $7''$, what would be the date of that observation expressed according to the conventional method of reckoning?

The 15th of April is the 105th day of the year; but 1864 being leap-year, it was the 106th of that particular year. By Table V. the decimal part for 106 days is 0·2904; therefore the date when reduced becomes 1864·290.

Example II.

According to the calculations of Seeling, the great comet of 1861 passed through perihelion on June 11·5508 G. M. T. What would that be, expressed in hours and minutes and seconds?

From Table VI. it appears that 0·5508 of a day corresponds to some period between 13^h and 14^h; being $0·0092^d$ in excess of the former.

From Table VII. it appears that 0·0092 of a day corresponds to some period between 13^m and 14^m; being $0·0002^d$ in excess of the former.

The difference between the decimals of 13^m and 14^m being $0·0007^d$, the given quantity is $\frac{2}{7}$ of a minute, or $17·142^s$ in excess of the 13^m.

And the whole answer is, June 11^d 13^h 13^m $17·14^s$.

Example III.

In 1864 (leap-year) how many days intervened between Jan. 5 and Aug. 12?

From Table VIII. it appears that Aug. 10 was the 253rd day of the year; therefore Aug. 12 was the 255th, and Jan. 5 being the 5th day of the year, the tabular interval is $255-5=250$, but 1864 being leap-year, the true interval was $250+1$, or 251 days.

IX., X., and XI. FOR DETERMINING THE DAY OF THE WEEK CORRESPONDING TO ANY DAY OF THE MONTH BETWEEN 1752 AND 1900.

COMMON YEARS.

	1761	1762	1757	1754	1755	1752	1753
	1767	1773	1763	1765	1766	1758	1759
	1778	1779	1774	1771	1777	1769	1770
	1789	1790	1785	1782	1783	1775	1781
	1795		1791	1793	1794	1786	1787
				1799	1800	1797	1798
	1801	1802	1803	1805	1806	1809	1810
	1807	1813	1814	1811	1817	1815	1821
	1818	1819	1825	1822	1823	1826	1827
January ..	4	5	6	2	3	7	1
February..	7	1	2	5	6	3	4
March ..	7	1	2	5	6	3	4
April ..	3	4	5	1	2	6	7
May ..	5	6	7	3	4	1	2
June ..	1	2	3	6	7	4	5
July ..	3	4	5	1	2	6	7
August ..	6	7	1	4	5	2	3
September	2	3	4	7	1	5	6
October ..	4	5	6	2	3	7	1
November	7	1	2	5	6	3	4
December	2	3	4	7	1	5	6
	1829	1830	1831	1833	1834	1837	1838
	1835	1841	1842	1839	1845	1843	1849
	1846	1847	1853	1850	1851	1854	1855
	1857	1858	1859	1861	1862	1865	1866
	1863	1869	1870	1867	1873	1871	1877
	1874	1875	1881	1878	1879	1882	1883
	1885	1886	1887	1889	1890	1893	1894
	1891	1897	1898	1895		1899	1900

X.

LEAP YEARS.

	1764 1792 1804	1768 1796 1808	1772 1812	1776 1816	1780 1820	1756 1784 1824	1760 1788 1828
January ..	7	5	3	1	6	4	2
February..	3	1	6	4	2	7	5
March ..	4	2	7	5	3	1	6
April ..	7	5	3	1	6	4	2
May ..	2	7	5	3	1	6	4
June ..	5	3	1	6	4	2	7
July ..	7	5	3	1	6	4	2
August ..	3	1	6	4	2	7	5
September	6	4	2	7	5	3	1
October ..	1	6	4	2	7	5	3
November	4	2	7	5	3	1	6
December	6	4	2	7	5	3	1
	1832 1860 1888	1836 1864 1892	1840 1868 1896	1844 1872	1848 1876	1852 1880	1856 1884

XI.

DAYS OF THE WEEK AND DAYS OF THE MONTH.

	1	2	3	4	5	6	7
Monday ..	1 8 15 22 29	7 14 21 28	6 13 20 27	5 12 19 26	4 11 18 25	31 3 10 17 24	30 2 9 16 23
Tuesday ..	2 9 16 23 30	1 8 15 22 29	7 14 21 28	6 13 20 27	5 12 19 26	4 11 18 25	31 3 10 17 24
Wednesday	3 10 17 24 31	2 9 16 23 30	1 8 15 22 29	7 14 21 28	6 13 20 27	5 12 19 26	4 11 18 25
Thursday ..	4 11 18 25	3 10 17 24 31	2 9 16 23 30	1 8 15 22 29	7 14 21 28	6 13 20 27	5 12 19 26
Friday ..	5 12 19 26	4 11 18 25	3 10 17 24 31	2 9 16 23 30	1 8 15 22 29	7 14 21 28	6 13 20 27
Saturday ..	6 13 20 27	5 12 19 26	4 11 18 25	3 10 17 24 31	2 9 16 23 30	1 8 15 22 29	7 14 21 28
Sunday ..	7 14 21 28	6 13 20 27	5 12 19 26	4 11 18 25	3 10 17 24 31	2 9 16 23 30	1 8 15 22 29

The 3 foregoing tables (from Willich) are useful for verifying dates (past or future) by inspection.

EXAMPLE.

The Battle of Waterloo was fought on June 18, 1815; what day of the week was that?

In the column in Table IX. containing the year 1815 the index-number belonging to the month of June is 4: then on referring to column 4 of Table XI., opposite 18 will be found 'Sunday.' So the Battle of Waterloo was fought on a Sunday[a].

The Battle of Trafalgar was fought on Oct. 21, 1805; what day of the week was that?

In the column in Table IX. containing the year 1805 the index-number belonging to the month of October is 2: then on referring to column 2 of Table XI., opposite 21 will be found 'Monday.' So the Battle of Trafalgar was fought on a Monday.

[a] A writer in the *New York Times* of April 10, 1862, shewed that in regard to battles fought on Sunday, the defeated side almost always was the one which began the conflict: in other words, the one which caused the desecration of the holy day. Waterloo is a case in point.

ON A NEW FORM OF CALENDAR[a], BY WHICH THE YEAR, OR MONTH, OR MONTH-DAY, OR WEEK-DAY MAY BE READILY FOUND WHEN THE OTHER THREE COMPONENTS OF A DATE ARE GIVEN.

THE Tabular Calendar annexed is perhaps as compact in form and simple in use as is possible. Its use may be stated thus:—Of the Year, Month, Day, and Week-day, given any three to find the fourth. If we arrange these thus,

	M	
D		W
	Y	

it is clear that M and D, Y, and W, will each fix one of the signs or hieroglyphs in the centre of the Table; and in order that the day of the month shall fall on a certain week-day in any given year, these signs must be the same. Thus, take the case of

	Apr.	
13		Mon.
	1874	

April 13, and Monday in 1874, both indicate *. We have now only to suppose one of these unknown to see that the sign indicated by the other pair will shew all the possible solutions. Thus:—

1. Y unknown; M and D indicate * (or any other sign, according to the case); W and * indicate Y.
2. M unknown; Y and W indicate *; D and * indicate M.
3. D unknown; Y and W indicate *; M and * indicate D.
4. W unknown; M and D indicate *; Y and * indicate W.

It is obvious that the signs are pure symbols for the occasion, and are for this very reason chosen heterogeneous so as not to have any *meaning* or *order*, *per se*.

It is only necessary to add that, where the date is known to fall in January or February of a bissextile year, the *italic* M (=Month) is to be used. Otherwise, or more generally, the *italic* M is *only* and *always* to be used with a bissextile Y. Thus:—

Thursday, January 1. What years?

Jan. 1 indicates × (or + if bissextile).

Thursday and × indicate 1801, 07, *not* 12, &c.

Thursday and + indicate 1824, 52, &c. *only*.

[a] By Capt. J. Herschel, R.E.

XII.

GENERAL CALENDAR TABLE.

Date.					Jan. Oct.	Apr. July *Jan.*	Sept. Dec.	June	Feb. Mar. Nov.	Aug. *Feb.*	May	
1	8	15	22	29	×	+	—	*	‖	‡	§	Monday.
2	9	16	23	30	§	×	+	—	*	‖	‡	Tuesday.
3	10	17	24	31	‡	§	×	+	—	*	‖	Wednesday
4	11	18	25	32	‖	‡	§	×	+	—	*	Thursday.
5	12	19	26		*	‖	‡	§	×	+	—	Friday.
6	13	20	27		—	*	‖	‡	§	×	+	Saturday.
7	14	21	28		+	—	*	‖	‡	§	×	Sunday.

Jan. Oct.	Apr. July *Jan.*	Sept. Dec.	June	Feb. Mar. Nov.	Aug. *Feb.*	May
1798	1799	1800	1801	1802	1803	...
1804	1805	1806	1807	...	1808	1809
1810	1811	...	1812	1813	1814	1815
...	1816	1817	1818	1819	...	1820
1821	1822	1823	...	1824	1825	1826
1827	...	1828	1829	1830	1831	...
1832	1833	1834	1835	...	1836	1837
1838	1839	...	1840	1841	1842	1843
...	1844	1845	1846	1847	...	1848
1849	1850	1851	...	1852	1853	1854
1855	...	1856	1857	1858	1859	...
1860	1861	1862	1863	...	1864	1865
1866	1867	...	1868	1869	1870	1871
...	1872	1873	1874	1875	...	1876
1877	1878	1879	..	1880	1881	1882
1883	...	1884	1885	1886	1887	...
1888	1889	1890	1891	...	1892	1893
1894	1895	...	1896	1897	1898	1899
1900	1901	1902	1903	...	1904	1905
						&c.

Rule.

Enter with month and date (or with year and week-day) for sign. This sign, in the same or another place, indicates the corresponding combination of year and week-day (or month and date), one of which being known indicates the other.

Note.

The *italic* months are for use in bissextile years only. No attention need be paid to leap years, unless the date falls in January or February.

XIII. MEAN REFRACTION OF CELESTIAL OBJECTS FOR TEMPERATURE 50°, AND PRESSURE 29·6 INCHES.

Alt.	Refr.	Alt.	Refr.	Alt.	Refr.	Alt.	Refr.	Alt.	Refr.
° ′	′ ″	° ′	′ ″	° ′	′ ″	° ′	′ ″	° ′	′ ″
0 0	33 0	3 0	14 36	6 0	8 28	9 0	5 48	14 0	3 45
5	32 10	5	14 20	5	8 21	5	5 45	10	3 43
10	31 22	10	14 4	10	8 15	10	5 42	20	3 40
15	30 36	15	13 39	15	8 9	15	5 39	30	3 38
20	29 50	20	13 34	20	8 3	20	5 36	40	3 35
25	29 6	25	13 20	25	7 57	25	5 34	50	3 33
30	28 23	30	13 6	30	7 51	30	5 31	15 0	3 30
35	27 41	35	12 53	35	7 45	35	5 28	10	3 28
40	27 0	40	12 40	40	7 40	40	5 25	20	3 26
45	26 20	45	12 27	45	7 35	45	5 23	30	3 24
50	25 42	50	12 15	50	7 30	50	5 20	40	3 21
55	25 5	55	12 3	55	7 25	55	5 18	50	3 19
1 0	24 29	4 0	11 51	7 0	7 20	10 0	5 15	16 0	3 17
5	23 54	5	11 40	5	7 15	10	5 10	10	3 15
10	23 20	10	11 29	10	7 11	20	5 5	20	3 12
15	22 47	15	11 18	15	7 6	30	5 0	30	3 10
20	22 15	20	11 8	20	7 2	40	4 56	40	3 8
25	21 44	25	10 58	25	6 57	50	4 51	50	3 6
30	21 15	30	10 48	30	6 53	11 0	4 47	17 0	3 4
35	20 46	35	10 39	35	6 49	10	4 43	10	3 3
40	20 18	40	10 29	40	6 45	20	4 39	20	3 1
45	19 51	45	10 20	45	6 41	30	4 34	30	2 59
50	19 25	50	10 11	50	6 37	40	4 31	40	2 57
55	19 0	55	10 2	55	6 33	50	4 27	50	2 55
2 0	18 35	5 0	9 54	8 0	6 29	12 0	4 23	18 0	2 54
5	18 11	5	9 46	5	6 25	10	4 20	10	2 52
10	17 48	10	9 38	10	6 22	20	4 16	20	2 51
15	17 26	15	9 30	15	6 18	30	4 13	30	2 49
20	17 4	20	9 23	20	6 15	40	4 9	40	2 47
25	16 44	25	9 15	25	6 11	50	4 6	50	2 46
30	16 24	30	9 8	30	6 8	13 0	4 3	19 0	2 44
35	16 4	35	9 1	35	6 5	10	4 0	10	2 43
40	15 45	40	8 54	40	6 1	20	3 57	20	2 41
45	15 27	45	8 47	45	5 58	30	3 54	30	2 40
50	15 9	50	8 41	50	5 55	40	3 51	40	2 38
55	14 52	55	8 34	55	5 52	50	3 48	50	2 37

Alt.	Refr.	Alt.	Refr.	Alt.	Refr.	Alt.	Refr.	Alt.	Refr.
° ′	′ ″	° ′	′ ″	° ′	′ ″	° ′	′ ″	° ′	′ ″
20 0	2 35	24 50	2 3	31 40	1 32	44 0	0 59	63 0	0 29
10	2 34	25 0	2 2	32 0	1 31	30	0 58	64 0	0 28
20	2 32	10	2 1	20	1 30	45 0	0 57	65 0	0 26
30	2 31	20	2 0	40	1 29	30	0 56	66 0	0 25
40	2 29	30	1 59	33 0	1 28	46 0	0 55	67 0	0 24
50	2 28	40	1 58	20	1 26	30	0 54	68 0	0 23
21 0	2 27	50	1 57	40	1 25	47 0	0 53	69 0	0 22
10	2 26	26 0	1 56	34 0	1 24	30	0 52	70 0	0 21
20	2 25	10	1 55	20	1 23	48 0	0 51	71 0	0 19
30	2 24	20	1 55	40	1 22	30	0 50	72 0	0 18
40	2 23	30	1 54	35 0	1 21	49 0	0 49	73 0	0 17
50	2 21	40	1 53	20	1 20	30	0 49	74 0	0 16
22 0	2 20	50	1 52	40	1 19	50 0	0 48	75 0	0 15
10	2 19	27 0	1 51	36 0	1 18	30	0 47	76 0	0 14
20	2 18	15	1 50	30	1 17	51 0	0 46	77 0	0 13
30	2 17	30	1 49	37 0	1 16	30	0 45	78 0	0 12
40	2 16	45	1 48	30	1 14	52 0	0 44	79 0	0 11
50	2 15	28 0	1 47	38 0	1 13	30	0 44	80 0	0 10
23 0	2 14	15	1 46	30	1 11	53 0	0 43	81 0	0 9
10	2 13	30	1 45	39 0	1 10	30	0 42	82 0	0 8
20	2 12	45	1 44	30	1 9	54 0	0 41	83 0	0 7
30	2 11	29 0	1 42	40 0	1 8	55 0	0 40	84 0	0 6
40	2 10	20	1 41	30	1 7	56 0	0 38	85 0	0 5
50	2 9	40	1 40	41 0	1 5	57 0	0 37	86 0	0 4
24 0	2 8	30 0	1 38	30	1 4	58 0	0 35	87 0	0 3
10	2 7	20	1 37	42 0	1 3	59 0	0 34	88 0	0 2
20	2 6	40	1 36	30	1 2	60 0	0 33	89 0	0 1
30	2 5	31 0	1 35	43 0	1 1	61 0	0 32	90 0	0 0
40	2 4	20	1 33	30	1 0	62 0	0 30		

XIV. CORRECTION OF MEAN REFRACTION.

Ap. Alt.	Height of the Thermometer.															
	20°	24°	28°	32°	36°	40°	44°	48°	5°	56°	60°	64°	68°	72°	76°	80°
° ′	′ +″	′ +″	′ +″	′ +″	+″	+″	+″	+″	−″	−″	−″	′ −″	′ −″	′ −″	′ −″	′ −″
0 0	2 40	2 18	1 55	1 33	1 11	51	31	10	10	29	48	1 7	1 25	1 43	2 1	2 19
0 10	2 32	2 12	1 49	1 28	1 8	48	29	10	9	27	45	1 4	1 21	1 38	1 54	2 12
0 20	2 25	2 5	1 44	1 24	1 4	46	28	9	9	26	44	1 1	1 17	1 33	1 49	2 05
0 30	2 18	1 59	1 39	1 20	1 1	44	26	9	8	25	41	58	1 13	1 28	1 43	1 59
0 40	2 11	1 53	1 34	1 16	58	42	25	8	8	24	39	55	1 10	1 24	1 38	1 53
0 50	2 5	1 48	1 29	1 12	55	40	24	8	8	23	37	52	1 6	1 20	1 34	1 48
1 0	1 59	1 43	1 25	1 9	53	38	23	8	7	21	36	50	1 3	1 17	1 30	1 43
1 10	1 53	1 38	1 21	1 6	50	36	22	7	7	20	34	48	1 0	1 13	1 26	1 38
1 20	1 48	1 33	1 17	1 3	48	34	21	7	6	19	32	45	57	1 9	1 21	1 33
1 30	1 43	1 29	1 14	1 0	46	32	20	7	6	18	31	43	54	1 6	1 18	1 29
1 40	1 39	1 25	1 11	57	44	31	18	6	6	18	30	41	52	1 4	1 15	1 25
1 50	1 35	1 21	1 8	55	42	30	17	6	6	17	28	39	50	1 1	1 11	1 21
2 0	1 31	1 18	1 5	53	39	29	17	6	5	16	27	37	48	58	1 8	1 18
2 20	1 23	1 11	1 0	48	37	26	16	5	5	15	25	35	44	54	1 3	1 11
2 40	1 17	1 6	55	44	34	24	14	5	5	14	23	32	41	50	58	1 6
3 0	1 11	1 1	51	41	32	22	13	4	4	13	21	30	38	46	54	1 1
3 20	1 6	57	47	38	29	21	13	4	4	12	20	28	35	43	50	0 57
3 40	1 2	53	44	36	28	20	12	4	4	11	18	26	33	40	47	53
4 0	58	49	41	33	26	18	11	4	4	10	17	24	31	37	44	50
4 30	53	45	38	31	24	17	10	3	3	9	16	22	28	34	40	45
5 0	48	41	35	28	22	16	9	3	3	9	14	20	26	31	36	40
5 30	45	38	32	26	20	14	9	3	3	8	13	19	24	29	34	38
6 0	41	35	30	24	19	13	8	3	2	7	12	17	22	26	31	35
6 30	38	33	28	22	17	12	7	2	2	7	11	15	20	24	29	33
7 0	36	31	26	21	16	12	7	2	2	6	10	14	19	23	27	31
8	32	27	23	19	15	10	6	2	2	5	9	13	16	20	24	27
9	28	24	20	16	13	9	5	2	2	5	8	11	14	18	21	24
10	26	22	18	15	12	8	5	2	1	4	7	10	13	16	19	22
11	23	20	17	14	11	8	5	2	1	4	7	9	12	15	18	20
12	21	18	15	13	10	7	4	1	1	4	6	9	11	13	16	18
13	20	17	14	12	9	7	4	1	1	3	6	8	10	12	15	17
14	18	16	13	11	8	6	4	1	1	3	5	7	9	11	14	16
15	17	15	12	10	8	6	3	1	1	3	5	7	9	11	13	15
16	16	14	12	9	7	5	3	1	1	3	5	6	8	10	12	14

Ap. Alt.	Height of the Thermometer.															
	20°	24°	28°	32°	36°	40°	44°	48°	52°	56°	60°	64°	68°	72°	76°	80°
°	+″	+″	+″	+″	+″	+″	+″	+″	−″	−″	−″	−″	−″	−″	−″	−″
17	15	13	11	9	7	5	3	1	1	3	4	6	8	9	11	13
18	14	12	10	8	6	5	3	1	1	2	4	6	7	9	10	12
19	13	11	9	8	6	4	3	1	1	2	4	5	7	8	10	11
20	13	11	9	7	6	4	2	1	1	2	4	5	6	8	9	11
25	10	8	7	6	5	3	2	1	1	2	3	4	5	6	7	8
30	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7
35	7	[illegible]	5	4	3	2	1	0	0	1	2	3	3	4	5	6
40	6	5	4	3	3	2	1	0	0	1	2	2	3	3	4	5
45	5	4	3	3	2	2	1	0	0	1	1	2	2	3	3	4
50	4	3	3	2	2	1	1	0	0	1	1	2	2	2	3	3
55	3	3	2	2	2	1	1	0	0	1	1	1	2	2	2	3
60	3	2	2	2	1	1	1	0	0	0	1	1	1	2	2	2
65	2	2	2	1	1	1	0	0	0	0	1	1	1	1	2	2
70	2	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1
80	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Height of Barometer.			− 28·26	− 28·56	− 28·85	− 29·15	− 29·45	+ 29·75	+ 30·05	+ 30·35	+ 30·64	+ 30·93			

In practical astronomy few tables are more constantly called into requisition than those relating to refraction: in fact, this correction may be regarded as the most important of those which have to be applied to instrumental readings.

Example I.

What is the correction for refraction for an altitude of 8° 5′, the thermometer standing at 50·0° and the barometer at 29·6° inches?

Answer (by inspection) .. .. 6′ 25″:

and therefore,

Apparent altitude	=	8° 5′	
Refraction	=	− 6	25″
True altitude		7 58	35

Example II.

What is the correction for refraction for the same altitude, the thermometer standing at 44° and the barometer at 29·45 inches?

			′	″
Thermometer correction for altitude 8° 5′	=	+	0	6
Barometer ditto	=	−	0	2
Correction for both is	=	+	0	4
Mean refraction	=	−	6	25
∴ True refraction	=	−	6	21

		°	′	″
Apparent altitude	=	8	5	0
True refraction	=	−	6	21
True altitude		7	58	39

THE MAJOR PLANETS.

Planet.	Symbol.	λ	ϖ	☊	ι	φ	ε	Sec. Var. ϖ	Sec. Var. Ω	Sec. Var. ι
		° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″		″	″	″
Mercury	☿	112 16 4	74 20 42	45 57 38	7 0 5	11 49 55	0·2054925	+ 643·56	− 782·27	+ 18·1828
Venus	♀	146 44 56	128 43 6	74 51 41	3 23 29	0 23 37	0·0068722	− 267·60	−1869·80	− 4·5522
Earth	⊕	100 53 30	99 30 29	0 0 0	0 0 0	0 57 43	0·0167917	+1177·81	..	..
Mars	♂	233 5 34	332 22 51	47 59 38	1 51 6	5 20 25	0·0931125	+1582·43	−2328·44	− 0·1523
Jupiter	♃	81 54 49	11 7 38	98 25 45	1 18 52	2 45 37	0·0481626	+ 663·86	−1577·57	−22·6087
Saturn	♄	123 6 29	89 8 20	111 56 7	2 29 36	3 13 6	0·0561501	+1943·07	−2266·46	−15·5131
Uranus	♅	173 30 37	167 30 24	72 59 21	0 46 28	2 40 23	0·0466686	+ 238·62	−3597·76	+ 3·1331
Neptune	♆	335 8 58	47 14 37	130 6 52	1 46 59	0 29 58	0·0087195	?	?	?
Sun	☉	..	..	..	..	..	..	..	..	..
Moon	☽	118 17 8	266 10 7	13 53 17	5 8 40	3 8 37	0·0549081	40° 39′ 45″	16° 19′ 42″	0

Symbol.	Sec. Var. ε	Semi-Axis Major. ⊕ = 1.	Daily Hel. Motion.	Sidereal Period.		Equinoctial P.	Synodic P.	Distance from ☉		
								Max.	Min.	Mean.
			° ′ ″	d.	y.	d.	d.	Miles.	Miles.	Miles.
☿	+0·000003867	0·3870985	4 5 32	87·969	0·240	87·968	115·87	42,665,000	28,119,000	35,392,000
♀	−0·000062711	0·7233317	1 36 7	224·700	0·615	224·695	583·92	66,585,000	65,677,000	66,131,000
⊕	+0·000041632	1·000000	0 59 8	365·256	1·000	365·242		92,965,000	89,894,000	91,430,000
♂	+0·000090176	1·523691	0 31 26	686·979	1·880	686·929	779·82	152,283,000	126,340,000	139,312,000
♃	+0·000159350	5·202798	0 4 59	4332·584	11·862	4330·610	398·8	498,603,000	452,782,000	475,693,000
♄	−0·000312402	9·538852	0 2 0	10759·219	29·458	10746·732	378·0	921,105,000	823,164,000	872,134,000
♅	−0·000025072	19·182730	0 0 42	30686·820	84·018	30589·357	369·7	1,835,700,000	1,672,001,000	1,753,851,000
♆	?	30·036280	0 0 21	60126·710	164·622	59742·710	367·5	2,770,217,000	2,722,325,000	2,746,271,000
☉	..	..	..	..	..	..	..	..	..	..
☽	0	—	13 10 35	27·32166	0·082	27·32158	29·53058	From ⊕ 251,947	From ⊕ 225,719	From ⊕ 238,833

*** These Tables are based upon an assumed solar parallax of 8″·94. Probably when the Transit of Venus observations of 1874 are completely discussed it will appear that this amount is somewhat too great. A parallax of 8″·92 would imply that the mean distance of the Earth from the Sun was 91,640,000 miles: a parallax of 8″·90, a mean distance of 91,850,000 miles.

THE MAJOR PLANETS.—*continued.*

Symbol.	Distance from ⊕ at Sup. ☌ for Inf. Planets, or at ☌ for Sup. Planets.			Distance from ⊕ at Inf. ☌ for Inf. Planets, or at ☍ for Sup. Planets.			Apparent Diameter.				Real Diameter.	
							From ⊕			From ☉		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Mean.	⊕ = 1.	Miles.
	Miles.	Miles.	Miles.	Miles.	Miles.	Miles.	″	″	″	″		
☿	135,631,000	118,014,000	126,822,000	64,845,000	47,229,000	56,037,000	12·9	4·5	8·7	17·3	0·374	2,962
♀	159,551,000	155,571,000	157,561,000	27,288,000	23,309,000	25,298,000	66·5	9·7	38·1	23·4	0·948	7,510
⊕	..	..	..	..	..	..	..	..	..	17·9	1·000	7,925
♂	245,249,000	216,235,000	230,742,000	62,388,000	33,375,000	47,882,000	30·4	4·1	17·3	7·3	0·621	4,920
♃	591,569,000	542,677,000	567,123,000	408,708,000	359,817,000	384,262,000	50·7	30·8	40·7	38·3	11·153	88,390
♄	1,014,070,000	913,059,000	963,564,000	831,210,000	730,198,000	780,704,000	20·3	14·6	17·5	17·0	9·073	71,904
♅	1,928,666,000	1,761,896,000	1,845,281,000	1,745,805,000	1,579,035,000	1,662,420,000	4·3	3·5	3·9	3·9	4·167	33,024
♆	2,863,182,000	2,812,220,000	2,837,701,000	2,680,322,000	2,629,359,000	2,654,841,000	2·9	2·6	2·8	2·8	4·621	36,620
☉	—	—	—	—	—	—	32′ 35″	31′ 31″	32′ 3″	—	107·582	852,584
☽	—	—	—	—	—	—	33 31	29 21	31 26	4·7	0·272	2,160

Symbol.	Surface.		Volume.		Mass.			Density.	
	⊕ = 1.	Square Miles.	⊕ = 1.	Cubic Miles.	☉ = 1.	⊕ = 1.	Tons.	⊕ = 1.	Water = 1.
☿	0·140	27,562,000	0·052	13,607,000,000	$\frac{1}{4869184}$	0·065	393,000,000,000,000,000,000	1·24	7·03
♀	0·898	177,186,000	0·851	221,778,000,000	$\frac{1}{401036}$	0·785	4,763,000,000,000,000,000,000	0·92	5·23
⊕	1·000	197,309,000	1·000	260,613,000,000	$\frac{1}{314760}$	1·000	6,069,000,000,000,000,000,000	1·00	5·67
♂	0·385	76,046,000	0·239	62,358,000,000	$\frac{1}{2548347}$	0·124	750,000,000,000,000,000,000	0·52	2·93
♃	124·396	24,544,610,000	1387·431	361,582,917,000,000	$\frac{1}{1046}$	300·857	1,825,900,000,000,000,000,000,000	0·22	1·23
♄	82·320	16,242,621,000	746·898	194,651,577,000,000	$\frac{1}{3496}$	90·032	546,406,000,000,000,000,000,000	0·12	0·68
♅	17·365	3,426,173,000	72·359	18,857,657,000,000	$\frac{1}{24900}$	12·641	76,721,000,000,000,000,000,000	0·18	0·99
♆	21·352	4,212,951,000	98·664	25,713,047,000,000	$\frac{1}{18780}$	16·761	101,720,000,000,000,000,000,000	0·17	0·96
☉	11573·789	2283,621,466,000	1,245,126·361	324,496,417,910,000,000	1	314760·000	1,910,278,070,000,000,000,000,000,000	0·25	1·43
☽	0·074	14,657,402	0·02034	5,300,000,000	$\frac{1}{24490744}$	0·0128	78,000,000,000,000,000,000	0·63	3·57

Symbol.	Apparent Diameter of ☉ to observer on Planet. ′	″	⊕ = 1.	Light and Heat of ☉ ⊕ = 1.	Axial Rotation. h.	m.	s.	Inclination of Axis to Plane of Ecliptic. °	′	Polar Compression.	Force of Gravity. Fall: Feet in 1 Sec.	⊕ = 1.	Orbital Velocity. Miles per hour.	Feet per sec.	⊕ = 1.	Velocity of Rotation at Equator. Miles per hour.	Feet per sec.	Time required for falling into the Sun, were gravitation free to exert its influence alone. Days.
☿	82	49	2·583	6·67	24	5	30	63	?	$\frac{1}{29}$	7·45	0·46	105,330	154,484	1·607	386	566	15·6
♀	44	19	1·383	1·91	23	21	23	73	32	very small	14·05	0·87	77,050	113,007	1·176	1,010	1,482	39·8
⊕	32	3	1·000	1·00	23	56	4	66	32	$\frac{1}{299}$	16·08	1·00	65,533	96,115	1·000	1,040	1,526	64·8
♂	21	2	0·656	0·43	24	37	23	61	18	$\frac{1}{55}$	4·88	0·30	53,090	77,866	0·810	628	921	121·8
♃	6	10	0·192	0·037	9	55	21	86	55	$\frac{1}{16·8}$	38·89	2·42	28,744	42,158	0·439	27,985	41,045	768·7
♄	3	22	0·105	0·011	10	29	17	61	50	$\frac{1}{9·22}$	17·59	1·09	21,221	31,124	0·324	21,538	31,589	1908·4
♅	1	40	0·052	0·003	9	30	?	?		?	11·71	0·73	14,963	21,945	0·228	10,921	16,017	5442·5
♆	1	4	0·033	0·001	?			?		?	12·62	0·79	11,958	17,538	0·182	?	?	10663·5
					d.	h.	m.											
☉	..	..	..	..	25	7	48	82	30	very small, if any.	437·31	27·20	..	..	..	4,407	6,463	..
☽	..	..	..	..	27	7	43	88	30	?	2·48	0·15	2,273	3,334	0·033	10	15	—

*** The epoch of the shifting elements on p. 897 is January 0, 1800 for the planets, and January 0, 1801 for the Moon.

The following elements of the planets Uranus and Neptune are by Professor Newcomb:—

	URANUS.		NEPTUNE.
Epoch	1850·0 G.	Epoch	1850·0 G.
λ =	29 12 43	λ =	335 5 38
ϖ =	170 38 48	ϖ =	43 17 30
☊ =	73 14 37	☊ =	130 7 31
ι =	0 46 20	ι =	1 47 0
ϵ =	0·0463592	ϵ =	0·0084962
a =	19·18338	a =	30·11157
Mean annual motion		=	2° 18470
Period =	30688·5076 days	=	60186·6385 days; 164·7820 Julian years.

No.	Name.	Discovered on	Discovered by	Discovered at	ϖ	☊	i
					° ′	° ′	° ′
1	Ceres	1801, Jan. 1	Piazzi	Palermo	149 38	80 47	10 37
2	Pallas......	1802, March 28	Olbers	Bremen	121 54	172 47	34 42
3	Juno	1804, Sept. 1	Harding	Lilienthal....	54 50	170 53	13 1
4	Vesta	1807, March 29	Olbers	Bremen	250 57	103 29	7 8
5	Astræa	1845, Dec. 8	Hencke	Driesen	134 57	141 28	5 19
6	Hebe	1847, July 1	Hencke	Driesen	15 16	138 43	14 47
7	Iris........	— Aug. 13	Hind	London	41 23	259 48	5 28
8	Flora	— Oct. 18	Hind........	London	32 54	110 18	5 53
9	Metis	1848, April 25	Graham	Markree	71 4	68 32	5 36
10	Hygeia	1849, April 12	De Gasparis..	Naples......	237 58	285 21	3 48
11	Parthenope	1850, May 11	De Gasparis..	Naples......	318 2	125 11	4 37
12	Victoria	— Sept. 13	Hind........	London	301 39	235 35	8 23
13	Egeria	— Nov. 2	De Gasparis	Naples......	120 10	43 12	16 32
14	Irene	1851, May 19	Hind........	London	180 11	86 41	9 8
15	Eunomia ..	— July 29	De Gasparis.	Naples......	27 52	293 52	11 44
16	Psyche	1852, March 17	De Gasparis	Naples......	15 8	150 29	3 4
17	Thetis	— April 17	Luther	Bilk	261 33	125 16	5 36
18	Melpomene	— June 24	Hind	London	15 6	150 4	10 9
19	Fortuna	— Aug 22	Hind	London	30 57	211 17	1 33
20	Massalia	— Sept. 19	De Gasparis	Naples......	99 2	206 24	0 41
21	Lutetia	— Nov. 15	Goldschmidt	Paris.......	327 4	80 28	3 5
22	Calliope	— Nov. 16	Hind........	London ...	59 28	66 36	13 44
23	Thalia......	— Dec. 15	Hind	London	123 44	67 37	10 14
24	Themis ...	1853, April 5	De Gasparis	Naples......	144 8	35 49	0 49
25	Phocea	— April 6	Chacornac ..	Marseilles ..	302 44	214 5	21 35
26	Proserpine..	— May 5	Luther	Bilk	236 25	45 55	3 36
27	Euterpe	— Nov. 8	Hind	London	87 59	93 51	1 36
28	Bellona ...	1854, March 1	Luther	Bilk	122 17	144 36	9 22
29	Amphitrite	— March 1	Marth	London	56 23	356 41	6 7
30	Urania	— July 22	Hind	London	31 13	308 8	2 6
31	Euphrosyne	— Sept. 1	Ferguson	Washington..	93 31	31 30	26 29
32	Pomona	— Oct. 26	Goldschmidt	Paris.......	193 22	220 43	5 29
33	Polyhymnia	— Oct. 28	Chacornac ..	Paris	342 17	9 4	1 56
34	Circe	1855, April 6	Chacornac ..	Paris.......	148 41	184 46	5 27
35	Leucothea ..	— April 19	Luther	Bilk	202 16	355 41	8 12

ϵ	μ	Period.	Semi-axis, Major.	Diameter.	App. opp. Star Mag.	Epoch. Berlin M.T.	Calculator.
	"	Years.	⊕'s = 1.	Miles.			
0·07631	770·78	4·604	2·7673	196	7·7	1874, Dec. 25·0 ..	Schubert.
0·23848	768·99	4·614	2·7716	171	8·0	— Nov. 1·0 ..	Farley.
0·25786	814·08	4·359	2·6683	124	8·5	— Nov. 1·0 ..	Hind.
0·08846	977·67	3·629	2·3616	214	6·6	— Dec. 7·0 ..	Farley.
0·18629	856·91	4·141	2·5786	57	10·0	— Dec. 7·0 ..	Farley.
0·20421	939·60	3·776	2·4250	92	8·6	— Sept. 15·0 ..	Luther.
0·23082	962·58	3·686	2·3862	88	8·6	1850, Jan. 0·0....	Brünnow.
0·15672	1086·33	3·266	2·2014	61	8·9	1848, Jan. 1·0....	Brünnow.
0·12332	962·34	3·687	2·3867	76	8·9	1858, June 30·0 ..	Lesser.
0·10950	636·42	5·575	3·1442	103	9·8	1873, Sept. 2·0 ..	Becker.
0·09937	923·62	3·842	2·4529	63	9·5	1874, Oct. 15·0 ..	Luther.
0·21892	994·83	3·567	2·3342	51	9·6	1831, Jan. 0·0 ..	Brünnow.
0·08710	857·95	4·136	2·5765	60	9·9	1850, Jan. 0·0 ..	Hansen.
0·16272	851·44	4·167	2·5896	65	9·7	1874, Dec. 14·0 ..	Bruhns.
0·18724	825·46	4·299	2·6437	92	9·1	1854, Jan. 0·0....	Schubert.
0·13907	711·00	4·991	2·9202	75	10·1	1874, July 23·0 ..	Schubert.
0·12908	912·39	3·889	2·4730	50	10·0	1873, Nov. 9·0 ..	Maywald.
0·21767	1020·12	3·478	2·2956	51	9·5	1854, Jan. 0·0....	Schubert.
0·15916	930·13	3·815	2·4414	56	9·7	1874, May 10·0 ..	Powalky.
0·14320	948·92	3·739	2·4091	65	9·3	— Aug. 7·0 ..	Schubert.
0·16210	933·55	3·801	2·4355	39	10·5	1853, Jan. 2·0....	Lesser.
0·09877	714·79	4·964	2·9100	78	10·0	1872, Dec. 20·5 ..	Maywald.
0·22968	831·83	4·266	2·6301	47	11·5	1873, Oct. 11·0 ..	Schubert.
0·12434	639·01	5·553	3·1357	24	11·0	1874, Dec. 6·0....	Krüger.
0·25581	954·72	3·717	2·3993	36	10·6	1873, Dec. 31·0 ..	Maywald.
0·08733	819·68	4·329	2·6561	44	10·7	1853, June 11·0 ..	Hoek.
0·17391	986·69	3·596	2·3472	50	9·7	1873, Jan. 5·0....	Hoppe.
0·15350	766·93	4·627	2·7765	65	10·1	1874, July 29·5 ..	Maywald.
0·10658	869·04	4·083	2·5253	83	9·1	1855, Jan. 0·0....	Becker.
0·03667	975·40	3·638	2·3653	44	10·0	1873, Dec. 29·0 ..	Maywald.
0·22274	635·48	5·584	3·1473	46	11·6	1874, May 16·0 ..	Schubert.
0·08301	852·59	4·162	2·5873	42	10·7	1855, Jan. 5·0....	Lesser.
0·33997	733·09	4·840	2·8613	36	11·6	1875, Jan. 6·0....	Schubert.
0·10728	805·82	4·403	2·6865	29	11·7	1873, June 9·0 ..	Auwers.
0·22370	685·48	5·176	2·9923	38	12·2	1874, Dec. 25·0 ..	Schubert.

No.	Name.	Discovered on	by	at	π	☊	i
					° ′	° ′	° ′
36	Atalanta ..	1855, Oct. 5	Goldschmidt	Paris	42 44	359 14	18 42
37	Fides	— Oct. 5	Luther	Bilk	66 4	8 15	3 7
38	Leda	1856, Jan. 12	Chacornac ..	Paris	101 5	296 24	6 57
39	Lætitia ...	— Feb. 8	Chacornac .	Paris	1 42	157 21	10 22
40	Harmonia ..	— March 31	Luther	Bilk	0 54	93 35	4 16
41	Daphne	— May 22	Goldschmidt	Paris	219 59	179 5	16 0
42	Isis	— May 23	Pogson	Oxford	317 58	84 28	8 35
43	Ariadne	1857, April 15	Pogson	Oxford	277 54	264 31	3 28
44	Nysa	— May 27	Goldschmidt	Paris	111 45	131 4	3 42
45	Eugenia	— June 28	Goldschmidt	Paris	229 24	148 7	6 36
46	Hestia	— Aug. 16	Pogson	Oxford	354 14	181 31	2 18
47	Melete	— Sept. 9	Goldschmidt	Paris	294 37	194 7	8 2
48	Aglaia	— Sept. 15	Luther	Bilk	312 44	4 11	5 1
49	Doris	— Sept. 19	Goldschmidt	Paris	70 19	185 4	6 29
50	Pales	— Sept. 19	Goldschmidt	Paris	31 32	290 33	3 8
51	Virginia...	— Oct. 4.	Ferguson	Washington .	10 1	173 28	2 48
52	Nemausa .	1858, Jan 22	Laurent . ..	Nismes... ..	174 35	175 44	9 57
53	Europa ...	— Feb. 6	Goldschmidt	Paris	106 37	129 45	7 27
54	Calypso ...	— April 4	Luther.	Bilk .. .	92 39	144 3	5 7
55	Alexandra ..	— Sept 10	Goldschmidt	Paris	294 16	313 49	11 47
56	Pandora....	— Sept. 10	Searle	Albany, U.S.	10 32	10 52	7 14
57	Mnemosyne	1859, Sept 22	Luther	Bilk	53 55	200 0	15 10
58	Concordia ..	1860, March 24	Luther	Bilk	189 10	161 20	5 2
59	Danae ...	— Sept 9	Goldschmidt	Châtillon	343 42	334 13	18 15
60	Olym. (Elpis)	— Sept. 12	Chacornac ..	Paris	18 19	170 20	8 37
61	Erato	— Sept. 14	Förster......	Berlin	38 27	125 43	2 12
62	Echo	— Sept. 14	Ferguson	Washington..	98 37	192 6	3 34
63	Ausonia	1861, Feb. 10	De Gasparis	Naples	270 11	337 58	5 48
64	Angelina .	— March 4	Tempel....	Marseilles .	123 37	311 10	1 20
65	Cybele ...	— March 8	Tempel.. ...	Marseilles ..	259 36	158 43	3 29
66	Maia	— April 9	H. P. Tuttle	Cambridge U.S.	46 21	8 17	3 5
67	Asia	— April 17	Pogson	Madras	306 32	202 38	5 59
68	Hesperia .	— April 29	Schiaparelli ..	Milan	108 10	187 3	8 28
69	Leto	— April 29	Luther	Bilk	345 6	44 53	7 58
70	Panopea.. ..	— May 5	Goldschmidt	Châtillon ...	299 49	48 18	11 38

ε	μ	Period.	Semi-axis, Major.	Diameter.	App. opp. Star Mag.	Epoch. Berlin M. T.	Calculator.
	"	Years.	⊕'s = 1.	Miles.			
0·30234	780·10	4·549	2·7452	18	12·9	1870, Jan. 0·0....	Schubert.
0·17468	825·60	4·298	2·6434	47	10·5	1874, Feb. 7·0....	Schubert.
0·15211	781·67	4·539	2·7415	40	11·1	— Jan. 3·0....	Maywald.
0·11260	769·90	4·609	2·7694	90	9·4	1872, Oct. 15·0 ..	Maywald.
0·04655	1039·34	3·414	2·2673	61	9·1	1863, Jan. 0·0....	Schubert.
0·27057	773·74	4·586	2·7602	61	10·2	1874, Jan. 10·5 ..	Maywald.
0·22561	930·91	3·812	2·4401	39	10·5	1856, June 11·0 ..	Brunn.
0·16708	1084·73	3·271	2·2035	33	10·2	1874, Sept. 17·0 ..	Prey.
0·15088	940·92	3·771	2·4227	42	10·3	— Jan. 20·0 ..	Powalky.
0·08324	791·00	4·486	2·7199	44	10·8	— Jan. 0·0....	Löwy.
0·16417	883·56	4·016	2·5265	25	11·6	1870, Jan. 0·0....	Karlinski.
0·23633	847·79	4·185	2·5970	29	11·5	1874, Oct. 21·0 ..	Luther.
0·13291	726·49	4·884	2·8786	43	11·2	— Jan. 15·0 ..	Powalky.
0·07176	646·05	5·492	3·1129	57	11·0	— Oct. 20·0 ..	Powalky.
0·23554	655·13	5·416	3·0840	61	10·8	— Dec. 25·0 ..	Powalky.
0·28597	821·71	4·318	2·6520	25	11·9	1874, July 19·0 ..	Powalky.
0·06723	975·47	3·637	2·3652	38	10·4	1873, May 5·0 ..	Tietjen.
0·10546	650·51	5·455	3·0986	72	10·5	1872, Jan. 1·0....	Murmann.
0·20259	836·34	4·243	2·6207	29	11·5	1873, Sept. 20·0 ..	Kochevill.
0·19869	795·63	4·460	2·7093	40	11·0	1858, Dec. 30·0 ..	Schultz.
0·14289	773·66	4·586	2·7604	44	10·9	1871, Oct. 23·0 ..	Moeller.
0·10930	633·01	5·352	3·1555	63	10·9	1866, Dec. 8·0 ..	Adolph.
0·04256	799·60	4·438	2·7004	31	11·6	1865, Jan. 7·0....	Oppolzer.
0·16104	686·73	5·167	2·9887	38	11·7	1874, April 6·0 ..	Luther.
0·11669	793·98	4·469	2·7131	36	11·3	1865, Jan. 7·0....	Oppolzer.
0·17343	640·90	5·536	3·1295	40	11·8	1874, Dec. 26·0 ..	Oppolzer.
0·18467	958·47	3·702	2·3930	17	12·2	1870, Jan. 0·0....	Peters.
0·12467	956·84	3·708	2·3958	49	9·9	1873, July 24·0 ..	Tietjen.
0·12819	808·31	4·390	2·6809	44	10·3	1865, Jan. 7·0....	Oppolzer.
0·11308	557·40	6·366	3·4347	63	11·3	1873, Jan. 25·0 ..	Fritsche.
0.16548	822·71	4·313	2·6495	18	12·7	1872, Aug. 25·6 ..	Schulhof.
0·18649	941·90	3·767	2·4210	22	11·6	1873, Oct. 11·0 ..	Maywald.
0·17108	690·46	5·139	2·9779	32	12·0	1871, Feb. 25·0 ..	Kowalczyk.
0·18827	765·28	4·637	2·7805	60	10·3	1864, Feb. 22·0 ..	Wolf.
0·18266	839·61	4·226	2·6139	36	11·1	1870, Sept. 18·0 ..	Dunér.

No.	Name.	Discovered on	by	at	π	☊	i
					° ′	° ′	° ′
71	Feronia ..	1861, May 29	C.H.F. Peters	Clinton, U.S...	307 58	207 49	5 24
72	Niobe ...	— Aug. 13	Luther	Bilk	221 23	316 21	23 20
73	Clytie	1862, April 7	Tuttle	Cambridge, U.S.	56 58	7 44	2 24
74	Galatea ..	— Aug. 30	Tempel......	Marseilles ...	7 49	197 44	4 0
75	Eurydice ..	— Sept. 22	C.H.F. Peters	Clinton, U.S...	335 16	359 48	5 1
76	Freia	— Oct. 21	D'Arrest	Copenhagen ..	92 42	212 5	2 3
77	Frigga	— Nov. 15	C.H.F. Peters	Clinton, U.S...	58 28	2 13	2 28
78	Diana ...	1863, March 15	Luther	Bilk	121 9	333 55	8 39
79	Eurynome	— Sept. 14	Watson	Ann Arbor, U.S.	44 16	206 35	4 37
80	Sappho....	1864, May 2	Pogson......	Madras	355 10	218 35	8 37
81	Terpsichore	— Sept. 30	Tempel......	Marseilles	48 34	2 36	7 56
82	Alcmene ..	— Nov. 27	Luther	Bilk	132 12	26 52	2 51
83	Beatrix....	1865, April 26	De Gasparis..	Naples	191 47	27 32	5 0
84	Clio	— Aug. 25	Luther	Bilk	339 29	327 24	9 23
85	Io	— Sept. 19	C.H.F. Peters	Clinton, U.S. .	322 35	203 56	11 53
86	Semele	1866, Jan. 4	Tietjen	Berlin	29 35	87 57	4 48
87	Sylvia ...	— May 17	Pogson......	Madras	337 23	76 27	10 47
88	Thisbe	— June 15	C.H.F. Peters	Clinton, U.S...	308 25	277 45	5 14
89	Julia	— Aug. 6	Stephan	Marseilles	353 18	311 33	16 11
90	Antiope ..	— Oct. 1	Luther	Bilk	301 38	71 20	2 17
91	Ægina	— Nov. 4	Stephan	Marseilles ...	80 15	10 59	2 8
92	Undina ..	1867, July 7	C.H.F. Peters	Clinton, U.S...	331 19	102 44	9 57
93	Minerva ..	— Aug. 24	Watson	Ann Arbor, U.S.	274 44	5 4	8 37
94	Aurora ...	— Sept. 6	Watson	Ann Arbor, U.S.	45 27	4 33	8 5
95	Arethusa ..	— Nov. 23	Luther	Bilk	31 16	244 22	12 52
96	Ægle	1868, Feb. 17	Coggia	Marseilles	163 10	322 50	16 7
97	Clotho	— Feb. 17	Tempel......	Marseilles	65 31	160 36	11 46
98	Ianthe ...	— April 18	C.H.F. Peters	Clinton, U.S. .	147 57	354 18	15 33
99	Dike......	— May 29	Borelly......	Marseilles	240 36	41 44	13 53
100	Hecate....	— July 11	Watson	Ann Arbor, U.S.	307 59	128 27	6 22
101	Helena ...	— Aug. 15	Watson	Ann Arbor, U.S.	327 59	343 41	10 11
102	Miriam....	— Aug. 22	C.H.F. Peters	Clinton, U.S...	354 41	211 37	5 5
103	Hera......	— Sept. 7	Watson	Ann Arbor, U.S.	321 19	136 10	5 24
104	Clymene ..	— Sept. 13	Watson	Ann Arbor, U.S.	58 14	44 14	2 52
105	Artemis ..	— Sept. 16	Watson	Ann Arbor, U.S.	242 38	187 57	21 32

ε	μ	Period.	Semi-axis, Major.	Diameter.	App. opp. Star Mag.	Epoch. Berlin M. T.	Calculator.
	"	Years.	⊕'s = 1.	Miles.			
0·11979	1040·15	3·411	2·2661		11·7	1870, Jan. 0·0.. ..	Peters.
0·17432	776·42	4·570	2·7539	71	10·2	1871, Oct. 13·0 ..	Becker.
0·04260	815·60	4·350	2·6649		11·7	— Dec. 2·0 ..	Powalky.
0·23600	763·33	4·648	2·7852		11·7	1874, March 19·5	Maywald.
0·30575	811·66	4·372	2·6735		12·4	— April 6·5 ..	Stockwell.
0·17422	563·65	6·295	3·4093		12·6	— Sept. 9·0 ..	Maywald.
0·13612	811·61	4·372	2·6737		12·6	1870, Jan. 0·0.. ..	Peters.
0·20534	835·14	4·249	2·6232		10·9	1873, Nov. 21·0 ..	Asten.
0·19447	928·87	3·820	2·4436		10·9	1874, July 20·0 ..	Reimann.
0·20010	1019·78	3·479	2·2961		11·1	1865, Dec. 3·0 ..	Albrecht.
0·21099	736·17	4·820	2·8533		11·1	1864, Oct. 6·0.. ..	Hall.
0·22034	771·89	4·597	2·7646		11·7	1875, Nov. 21·0 ..	Safford.
0·08595	936·66	3·788	2·4301		11·6	1870, Oct. 28·0 ..	Becker.
0·23644	977·60	3·630	2·3617		12·0	1869, May 26·0 ..	Valentiner.
0·19115	820·69	4·323	2·6539		10·4	1870, Jan. 0·0.. ..	Peters.
0·21012	646·32	5·490	3·1120		13·1	1871, Dec. 2·0 ..	Anderson.
0·07580	544·67	6·514	3·4881		11·4	1866, May 16·0 ..	Peters.
0·16318	770·76	4·604	2·7673		11·6	1871, Oct. 3·0.. ..	Kowalczyk.
0·18053	870·84	4·075	2·5510		10·7	1866, Oct. 29·0 ..	Wolf.
0·17207	639·24	5·551	3·1349		12·4	1874, Jan. 5·0.. ..	Maywald.
0·10872	851·50	4·167	2·5895		11·9	— Sept. 11·0 ..	Oppolzer.
0·10239	624·19	5·685	3·1851		10·6	1871, April 6·0 ..	Anderson.
0·14054	776·49	4·570	2·7537		11·6	1872, Nov. 6·0 ..	Lehmann.
0·08699	631·41	5·620	3·1608		10·8	1873, Nov. 1·5 ..	Leppig.
0·14546	656·89	5·402	3·0785		11·3	1872, Sept. 7·0 ..	Schur.
0·14047	666·22	5·326	3·0497		11·1	1873, March 6·0..	Schulhof.
0·25812	814·58	4·356	2·6672		11·1	1874, July 4·5 ..	Maywald.
0·18961	805·21	4·407	2·6878		12·8	1870, Jan. 0·0.. ..	Peters.
0·23839	758·66	4·677	2·7967			1868, June 5·0 ..	Loewy & Tisser.
0·15652	650·75	5·453	3·0978		11·6	— July 10·0	Stark.
0·13920	854·06	4·155	2·5843		11·8	— Aug. 15·5 ..	Watson.
0·25510	817·47	4·341	2·6609		12·9	1870, Jan. 0·0.. ..	Peters.
0·08363	798·85	4·442	2·7020		9·9	1872, July 29·0 ..	Leveau.
0·17727	634·31	5·594	3·1512		11·0	1868, Sept. 13·5 ..	Watson.
0·17284	968·74	3·663	2·3761		11·7	— Sept. 28·0..	Watson.

No.	Name.	Discovered on	Discovered by	Discovered at	π	☊	i
					° ′	° ′	° ′
(106)	Dione	1868, Oct. 10	Watson	AnnArbor, U.S.	27 14	63 17	4 38
(107)	Camilla ..	— Nov. 17	Pogson	Madras	112 50	175 41	9 48
(108)	Hecuba ..	1869, April 2	Luther	Bilk	173 49	352 17	4 24
(109)	Felicitas .	— Oct. 9	C. H. F. Peters	Clinton, U.S...	56 1	4 58	8 3
(110)	Lydia	1870, April 19	Borelly..	Marseilles	331 45	57 8	5 59
(111)	Ate	— Aug. 14	C. H. F. Peters	Clinton, U.S...	108 33	306 13	4 57
(112)	Iphigenia	— Sept. 19	C. H. F. Peters	Clinton, U.S...	338 9	324 3	2 37
(113)	Amalthæa	1871, March 12	Luther	Bilk	199 11	123 5	5 2
(114)	Cassandra	— July 23	C. H. F. Peters	Clinton, U.S....	153 6	164 24	4 55
(115)	Thyra	— Aug. 6	Watson	AnnArbor, U.S.	43 3	308 57	11 35
(116)	Sirona	— Sept. 8	C. H. F. Peters	Clinton, U.S...	152 55	64 19	3 35
(117)	Lomia ..	— Sept. 12	Borelly......	Marseilles ...	48 37	349 30	14 57
(118)	Peitho	1872, March 15	Luther	Bilk	77 20	47 26	7 48
(119)	Althæa ..	— April 3	Watson ...	AnnArbor, U.S.	12 46	203 54	5 47
(120)	Lachesis ..	— April 10	Borelly......	Marseilles ...	220 19	342 40	7 0
(121)	Hermione..	— May 12	Watson	AnnArbor, U.S.	0 29	76 55	7 35
(122)	Gerda	— July 31	C. H. F. Peters	Clinton, U.S...	208 38	178 55	1 36
(123)	Brunhilda	— July 31	C. H. F. Peters	Clinton, U.S...	71 52	308 42	6 29
(124)	Alceste....	— Aug. 23	C. H. F. Peters	Clinton, U.S...	245 34	188 17	2 56
(125)	Liberatrix	— Sept. 11	Prosper Henry	Paris	251 10	171 10	6 5
(126)	Velleda ..	— Nov. 5	Paul Henry ..	Paris	347 46	23 7	2 56
(127)	Johanna ..	— Nov. 5	Prosper Henry	Paris	122 55	31 42	8 17
(128)	Nemesis	Nov. 25	Watson	AnnArbor, U.S.	12 15	76 39	6 15
(129)	Antigone ..	1873, Feb. 5	C. H. F. Peters	Clinton, U.S...	240 49	138 1	12 11
(130)	Electra ...	— Feb. 17	C. H. F. Peters	Clinton, U.S...	20 13	146 3	22 56
(131)	Vala	— May 24	C. H. F. Peters	Clinton, U.S...	258 26	65 10	4 39
(132)	Æthra	— June 13	Watson ...	AnnArbor, U.S.	152 11	259 44	25 0
(133)	Cyrene . ..	— Aug. 16	Watson	AnnArbor, U.S.	247 52	321 7	7 14
(134)	Sophrosyne	— Sept. 27	Luther	Bilk	66 44	346 22	11 36
(135)	Hertha ...	1874, Feb. 18	C. H. F. Peters	Clinton, U.S...	319 50	343 59	2 19
(136)	Austria ..	— March 18	Palisa	Pola	307 12	186 9	9 41
(137)	Melibœa ..	— April 21	Palisa	Pola	310 20	204 18	13 46
(138)	Tolosa ...	— May 19	Perrotin	Toulouse	310 1	55 8	3 17
(139)	Juewa	— Oct. 10	Watson	Pekin	115 32	358 37	8 19
(140)	Siwa	— Oct. 13	Palisa	Pola	197 18	107 15	3 10

ϵ	μ	Period.	Semi-axis, Major.	Diameter.	App. opp. Star Mag.	Epoch. Berlin M.T.	Calculator.
	"	Years.	⊕'s = 1.	Miles.			
0·18288	631·50	5·619	3·1605		11·0	1869, Jan. 0·0 ..	Seydler.
0·12271	528·20	6·718	3·5602		12·40	1868, Dec. 19·5 ..	Tietjen.
0·10052	616·59	5·755	3·2113		11·3	1871, Sept. 13·0 ..	Schulhof.
0·29882	801·90	4·425	2·6952		11·5	1875, Jan. 31·5 ..	Rogers.
0·07976	781·84	4·538	2·7402		11·4	1874, Feb. 9·5 ..	Oppenheim.
0·10600	849·36	4·178	2·5938		11·6	1873, May 5·0 ..	Holetschek.
0·12856	934·68	3·796	2·4335		10·9	1874, Oct. 27·5 ..	Rogers.
0·08778	968·47	3·664	2·3765		11·4	— Jan. 0·0 ..	Oppolzer.
0·14011	810·63	4·377	2·6758		10·1	— Jan. 0·0 ..	Anton.
0·19387	966·92	3·670	2·3791		10·7	— May 20·0 ..	Watson.
0·14395	771·27	4·601	2·7661		10·6	— May 8·0 ..	Tisserand.
0·02288	686·03	5·172	2·9907		12·0	1871, Sept. 15·5 ..	Wijkander.
0·16457	932·27	3·806	2·4377		11·1	1872, March 31·0	Smekal.
0·08394	856·19	4·144	2·5800			— May 1·5 ..	Watson.
0·05440	640·17	5·543	3·1319		12·8	— May 1·0 ..	Pechüle.
0·12370	550·72	6·443	3·4625		10·3	— June 9·5 ..	Watson.
0·05717	614·19	5·777	3·2196		11·6	1875, Jan. 1·5....	Stockwell.
0·11331	803·12	4·418	2·6925			1872, Jan. 0·0 ..	Peters.
0·07844	832·08	4·264	2·6296		10·5	— Aug. 26·5 ..	Hall.
0·34675	670·99	5·288	3·0352			— Sept. 12·0 ..	Leveau.
0·10612	930·98	3·811	2·4399			1874, Jan. 0·0 ..	Henry.
0·06275	776·37	4·570	2·7540		11·4	— April 17·0..	Renan.
0·12565	778·03	4·561	2·7500		11·0	1873, Feb. 25·5 ..	De Ball.
0·20760	727·61	4·877	2·8757		9·1	1874, Jan. 0·0 ..	Austin.
0·20405	640·83	5·537	3·1298		11·9	— Jan. 0·0	Austin.
0·08145	942·40	3·765	2·4202		12·2	— Oct. 23·0 ..	Stockwell.
0·38196	845·87	4·195	2·3581			{1873, June 20·5 (Washington)}	Watson.
0·13653	661·31	5·365	3·0648			— Oct. 17·5 .	Tietjen.
0·11722	862·57	4·114	2·5673			1874, Jan. 0·0 ..	Porter.
0·20464	937·11	3·786	2·4292			— Feb. 25·0 ..	Anderson.
0·11325	1014·93	3·496	2·3035			— April 4·4 ..	Tietjen.
0·20848	639·70	5·547	3·1334			— April 21·5..	Schulhof.
0·13397	953·03	3·724	2·4022			1875, Oct. 21·0 ..	Perrotin.
0·05132	751·64	4·732	2·8140			— Oct. 14·5 ..	Doolittle.
0·19787	796·69	4·454	2·7069			1874, Dec. 1·5 ..	Schulhof.

No.	Name.	Discovered on	Discovered by	Discovered at	π	☊	ι
					° ′	° ′	° ′
141	Lumen	1875, Jan. 13	Paul Henry ..	Paris	22 34	318 59	11 33
142	Polana	— Jan. 28	Palisa	Pola	227 23	292 36	2 18
143	Adria	— Feb. 23	Palisa	Pola	249 35	333 41	11 32
144	Vibilia	— June 3	C. H. F. Peters	Clinton, U.S.	8 31	76 45	4 51
145	Adeona ..	— June 3	C. H. F. Peters	Clinton, U.S.	118 8	77 43	14 24
146	Lucina	— June 8	Borelly	Marseilles	237 3	84 22	12 42
147	Protogeneia	— July 10	Schulhof	Vienna	84 43	252 29	1 57
148	Gallia	— Aug. 7	Prosper Henry	Paris	36 4	145 13	25 40
149	Medusa ..	— Sept. 21	Perrotin	Toulouse			
150	Nuwa	— Oct. 19	Watson	Ann Arbor, U.S.	16 56	207 55	2 2
151	Abundantia	— Nov. 1	Palisa	Pola	215 57	40 2	7 52
152	Atala	— Nov. 2	Paul Henry ..	Paris	80 0	41 28	12 10
153	Hilda	— Nov. 2	Palisa	Pola	285 1	228 20	7 50
154	Bertha	— Nov. 6	Prosper Henry	Paris	168 41	37 36	20 49
155	Scylla	— Nov. 8	Palisa	Pola			
156	Xantippe ..	— Nov. 22	Palisa	Pola	155 58	246 11	7 29
157	Dejanira ..	— Dec. 1	Borelly	Marseilles	109 12	62 24	11 49
158	Coronis ..	1876, Jan. 4	Knorre	Berlin	355 10	282 49	1 23
159	Æmilia ..	— Jan. 26	Paul Henry ..	Paris			
160	Una	— Feb. 20	C. H. F. Peters	Clinton, U.S.	56 50	9 18	3 51
161	Alhor	— April 18	Watson	Ann Arbor, U.S.	312 56	18 33	9 10
162		— April 21	Prosper Henry	Paris	147 44	38 15	6 3
163	Erigone ..	— April 26	Perrotin	Toulouse	93 17	158 50	4 41
164	Eva	— July 12	Paul Henry ..	Paris			
165	Loreley ..	— Aug. 10	C. H. F. Peters	Clinton, U.S.			
166	Rhodope ..	— Aug. 10	C. H. F. Peters	Clinton, U.S.			
167	Urda	— Aug. 28	C. H. F. Peters	Clinton, U.S.			
168	Sibylla	— Sept. 27	Watson	Ann Arbor, U.S.			
169	Zelia	— Sept. 28	Prosper Henry	Paris			

ε	μ	Period.	Semi-axis, Major.	Diameter.	App. opp. Star Mag.	Epoch. Berlin M. T.	Calcula
	″	Years.	⊕'s = 1.	Miles.			
0·22331	795·58	4·460	2·7095			1875, Feb. 25·0 ..	Renan.
0·10540	962·02	3·688	2·3872			— Jan. 28·0 ..	Knorre.
0·06353	777·00	4·567	2·7525			— Mar. 25·5 ..	Knorre.
0·22863	826·08	4·295	2·6423			— June 29·5 ..	C. H. F. P
0·21270	802·49	4·422	2·6939			— Jan. 0·0 ..	Porter.
0·06918	796·34	4·456	2·7077			— July 1·0 ..	Stéphan.
0·02960	642·17	5·525	3·1254			— July 11·5 ..	Schulhof.
0·18437	764·26	4·643	2·7830			— Sept. 1·0 (Greenwich)	Bossert.
0·13756	668·18	5·310	2·9845			— Oct. 27·56 ..	A. Schmidt
0·09977	854·17	4·154	2·5841			— Nov. 8·5 ..	A. Schmidt
0·08222	640·14	5·543	3·1320			— Nov. 13·5 (Greenwich)	Bossert.
0·16303	451·90	7·852	3·9504			1876, Jan. 0·0 ..	Kühnert.
0·10007	613·79	5·781	3·2210			1875, Nov. 22·5 ..	A. Schmidt
0·26370	670·23	5·294	3·0375			— Nov. 27·38	A. Schmidt
0·21984	853·39	4·158	2·5857			1875, Dec. 26·4 (Greenwich)	Stéphan.
0·29201	686·23	5·171	2·9901			1876, Jan. 4·5 ..	A. Schmidt
0·06040	785·14	4·519	2·7334			— Jan. 0·0 ..	Peters.
0·13288	968·82	3·662	2·3760			— May 21·5 ..	A. Schmidt
0·16534	675·71	5·251	3·0211			— May 19·47	V. Knorre.
0·14905	982·10	3·613	2·3545			— May 27·5 ..	Tietjen.

VOCABULRAY OF DEFINITIONS, &c.

*** In making use of this, the General Index must be consulted at the same time, for many things are defined in the Text of this volume, to allude again to which here would be a vain repetition. Of the Arabic names of the Stars a limited number only are given, and even many of these have virtually fallen into disuse.

A.

Abbreviations often used by Astronomers:

Alt.	Altitude.
A.M.	Ante Meridiem.
B.A.C.	British Association Catalogue.
B.M.T.	Berlin Mean Time.
Cat.	Catalogue.
Decl.	Declination.
Deg.	Degree.
Diam.	Diameter.
Diff.	Difference.
Dist.	Distance.
Ep.	Epoch.
♅.	Sir W. Herschel.
G.M.T.	Greenwich Mean Time.
Groom.	Groombridge's Catalogue of Stars.
h.	Hour.
h.	Sir J. Herschel.
Mag.	Magnitude of Star.
M.	Messier's Catalogue of Nebulæ.
M.T.	Mean Time.
m.	Minute of Time.
N.P.D.	North Polar Distance.
nf.	North and following.
np.	North and preceding.
N.S.	New Style.
O.S.	Old Style.
P.M.	Post Meridiem.
Pos.	Angle of Position.
s.	Second of Time.
Σ.	W. Struve's Catalogue of Double Stars, or Struve himself.
sf.	South and following.
Sm.	Admiral W. H. Smyth.
sp.	South and preceding.

Aberration, (*aberrare*, to wander from).

Achernar, a star otherwise called α Eridani.

Achromatic (α without, and χρῶμα colour). A refracting telescope is said to be achromatic when the lenses are so combined that an image practically destitute of colour is obtained.

Acolyte (ἀκόλουθος, an attendant); a term sometimes used to designate the smaller of two stars placed in close contiguity.

Acronical (ἀκρόνυχος, at nightfall). A heavenly body is said to rise or set acronically when it rises or sets at sunset.

Acubene, a star otherwise known as α Cancri.

Adara, a star otherwise called ε Canis Majoris.

Adjustment (*ad* to, and *justus* just); the operation of bringing all the parts of an instrument into their proper relative position for use.

Aërolite (ἀήρ the air, λίθος a stone).

Æstival (*æstas*, summer), relating to the summer.

Albedo of a planet: "the proportion diffusedly reflected by an element of surface of the solar light incident on such element." (*Month. Not.* R.A.S., vol. xx. p. 103; xxi. p. 198.)

Albireo, a star otherwise called β Cygni.

Alchiba, a star otherwise called α Corvi.

Alcor, a star otherwise known as ρ Ursæ Majoris.

Alcyone, a star in the Pleiades, otherwise called η Tauri.

Aldebaran, a star otherwise called α Tauri.

Alderamin, a star otherwise called α Cephei.

Algeiba, a star otherwise called γ^1 Leonis.

Algenib, a star otherwise called γ Pegasi. The star α Persei sometimes bore this name.

Algol, a well-known variable star, otherwise called β Persei.

Algorab, a star otherwise called α Corvi.

Alhena, a star otherwise called γ Geminorum.

Alidad; the cross-bar carrying the verniers of a graduated circle. The word, which is not often met with, is of Arabic origin, and was formerly applied to the moveable index of an astrolabe.

Alioth, a star otherwise called ϵ Ursæ Majoris.

Alkaid, a star otherwise called η Ursæ Majoris.

Alkes, a star otherwise known as α Crateris.

Almaac, a star otherwise called γ Andromedæ.

Almacantars, a name for circles of altitude parallel to the horizon.

Almacantar Staff, an instrument formerly used for determining the amplitude of an object.

Alnilam, a star otherwise called ϵ Orionis.

Alphard, a star otherwise called α Hydræ.

Alphecca, a star otherwise called α Coronæ Borealis.

Alpheratz, a star otherwise called α Andromedæ.

Alphirk, a star otherwise called β Cephei.

Alshain, a star otherwise called β Aquilæ.

Altair, a star otherwise called α Aquilæ.

Altazimuth Instrument. See p. 695.

Altitude (*altitudo*, height); the angular elevation of a heavenly body above the horizon measured towards the zenith on any great circle.

Alwaid, a star otherwise called β Draconis.

Amplitude (*amplitudo*, extent); the angular distance of a heavenly body from the East or West point of the horizon, measured on the horizon.

Analemma, a scale painted on globes, and having reference to the motion of the Sun.

Angle (*angulus*, a corner); the inclination of two straight lines to each other in the same plane gives rise to *a plane rectilineal angle*, or simply *an angle*. When a straight line, standing on another straight line, makes the adjacent angles equal to each other, each of those angles is called a *right* angle; but if the adjacent angles are not equal to each other, then the greater is called an *obtuse* and the lesser an *acute* angle.

Angle of eccentricity. See p. 41.

Angle of position (chiefly used with reference to double stars). This is the angle formed by a line joining two stars with the meridian line which passes through the larger one. It is reckoned from 0° to 360° from the North point of the field of the telescope, by East, South, and West, round to North again.

Angle of situation; a term introduced by Sir J. Herschel to indicate the angle formed at any star by arcs passing through the zenith and the Pole respectively. This angle, sometimes called the parallactic angle, was formerly known as the "angle of position," but it has been thought best to limit this term as above.

Angular velocity of any heavenly body is the rate of increase or decrease of the angle contained between the radius vector of the body and a fixed straight line.

Annual equation. See p. 80.

Annual Variation in the right ascension or declination of a star is the change produced in either element by the combined effects of precession of the equinoxes and the proper motion of the star.

Annular (*annulus*, a ring); a term applied to a certain kind of solar eclipse, because the appearance presented is a ring of light.

Anomalistic Period; the time of revolution of a planet in reference to its line of *apsides* (q. v.) In the case of the Earth, the period is called the *anomalistic year;* in the case of the Moon, the *anomalistic month.*

Anomaly (α not, and ὁμαλός even), *eccentric.* "An auxiliary angle employed to abridge the calculations connected with the motion of a planet or comet in an elliptic orbit. If a circle be drawn, having its centre coincident with that of the ellipse, and a diameter equal to the transverse [major] axis of the latter, and if from this axis a perpendicular be drawn through the true place of the body in the ellipse to meet the circumference of the circle, then the eccentric anomaly will be the angle formed by a line drawn from the point where the perpendicular meets the circle, to the centre, with the longer diameter of the ellipse."—*Hind.*

Anomaly, mean; the angular distance of a planet or comet from the perihelion or aphelion, supposing it to have moved with its *mean* velocity.

Anomaly, true; the *true* angular distance of a comet or planet from perihelion or aphelion.

Ansæ (*ansa*, a handle); a term applied to those opposite extremities of the ring of Saturn which, viewed foreshortened from the Earth, appear as projections or handles to the ball.

Antares (ἀντί opposed to, Ἄρης, Mars, *i.e.* rivalling Mars), a red star, otherwise called α Scorpii.

Antipodes (ἀντί opposite, and πόδες feet); those inhabitants of the Earth who live under opposite meridians and opposite parallels of latitude, who walk therefore *feet to feet*.

Aperture (*apertus*, uncovered); that portion of the object-glass (or mirror, as the case may be) of a telescope which is actually available for the scrutiny of an object. It is usually expressed in the form of the linear measure of the diameter.

Aphelion (ἀπό from, ἥλιος the Sun); that point in the orbit of a planet or comet farthest from the Sun.

Aplanatic (α without, and πλάνη error); free from error. The term is in strictness applicable to any optical instrument in which the spherical and chromatic aberrations are duly corrected.

Apogee (ἀπό from, γῆ the Earth); the correlative of aphelion, applied in two general senses, (1) to that point of the Moon's orbit farthest from the Earth; (2) to that point of the Earth's orbit farthest from the Sun.

Apo-Saturnium; the point in the orbit of a satellite of Saturn most remote from the primary.

Apparent (*apparere*, to appear at); employed astronomically as the opposite to "true" or "real." Thus, the apparent sunset differs from the real sunset in consequence of the effect of refraction. The apparent equinox differs from the real equinox in consequence of the effect of nutation. The apparent position of a star differs from the real position in consequence of the effect of refraction, aberration, nutation, &c.

Apparition, circle of perpetual; a circle of declination which separates the portion of the heavens which at a particular latitude does not go below the horizon from that which does.

Appulse (*appellere*, to drive towards); the near approach of two heavenly bodies.

Apsis (ἀψίς, an arch); applied to the opposite extremities of a planetary or cometary orbit, which are also its points of perihelion and aphelion. So the *line of Apsides* is the line joining these two points, which is also the major-axis of the ellipse.

Arc (*arcus*, a bow); a part of any curved surface.

Arc, diurnal; that part of a circle parallel to the equator which is apparently described by the Sun between sunrise and sunset.

Arc, nocturnal; the converse of the preceding.

Arc of progression; the arc of the ecliptic described by a planet when moving in the order of the signs, or from West to East.

Arc of retrogradation; the converse of the preceding.

Arctophylax (ἄρκτος a bear, and φύλαξ a keeper); the "Bear-keeper"—an ancient name for the constellation Boötes.

Arcturus (ἄρκτος a bear, and οὐρά a tail), a star pointed at the tail of the Great Bear, otherwise called α Boötis.

Argument (*argumentum*, a thing taken for granted) is a term used to denote any mathematical quantity on which another depends or by which another may be found.

Arided, a star otherwise known as α Cygni.

Aries, first point of; the origin or station from which are reckoned right ascensions on the equator and longitudes on the ecliptic.

Armillary Sphere (*armilla*, a bracelet); an instrument made up of a number of circles of metal crossing one another and representing the various imaginary circles of geographers and astronomers. It was thought to be useful for assisting students in realising dispositions and motions of the heavenly bodies.

Arneb, a star otherwise called α Leporis.

Ascension, oblique. The oblique ascension is the arc of the equator between the first point of Aries and the point of the equator which rises with a heavenly body, reckoned forwards according to the order of the signs. The converse word is "descension," but it is obsolete.

Ascension, right. The right ascension of a heavenly body is its distance from the first point of Aries reckoned on the equator. It is so called because in a right sphere the meridian passing through the object will coincide with the horizon when the object is rising or setting.

Ascensional Difference is the difference between the right and oblique ascensions.

Asterism (ἀστήρ, a star); a group or collection of stars; a constellation.

Asteroid (ἀστήρ a star, and εἶδος a form); star-like. A name applied to the minor planets, but now going out of use.

Astral (ἀστήρ, a star); anything relating to the stars.

Astrolabe (ἀστήρ a star, and λαμβάνω I take); an astronomical instrument invented by Hipparchus, designed to represent the various circles of the sphere. An old-fashioned instrument used in navigation also bore this name.

Astrology (ἀστήρ a star, and λόγος a word); identical with astronomy in grammatical meaning, but conventionally applied to the science (or delusion) of fortune-telling by aid of the stars.

Astrometry (ἀστήρ a star, and μέτρον a measure); conventionally applied to the measurement of the apparent magnitudes of stars. *Photometry* (q. v.) is used in a similar sense. Hence the words *Astrometer* and *Photometer* as names of instruments.

Astronomy (ἀστήρ a star, and νόμος a law); the science of the laws of the stars.

Astroscope (ἀστήρ a star, and σκοπέω I view); an instrument invented in 1698 by Shukhard of Tubingen for facilitating the study of the constellations, but now obsolete.

Augmentation of the Moon's semi-diameter is the increase due to the distance of the Moon from the observer being less than its distance from the centre of the Earth, to which calculations are referred.

Axis (ἄξων, an axle); an imaginary line joining the North and South poles of a planet, and upon which it is assumed to revolve.

Azimuth (*samatha* to go towards, *Aratic*); the angular distance of an object from the North or South points of the horizon, or the angle formed with the meridian by a great circle passing through the zenith and the object.

B.

Base-line, a term used in Land Surveying to indicate a line measured with great exactness, so that it may serve as the foundation (basis) of a series of triangles to connect together objects far removed from one another.

Bellatrix, a star otherwise called γ Orionis.

Benetnasch, a star otherwise called η Ursæ Majoris.

Betelgeuse, a star otherwise called α Orionis.

Bifid (*bi-fidus*, cleft into two parts); a term applied to the tails of comets when they appear as if split in a longitudinal direction.

Binary (*binarius*, twofold). Two stars revolving round each other are said to form a binary system. Two stars *not* so revolving are simply said to form a "double."

Binocular (*bis* twice, and *oculus* an eye); double-eyed: a form of telescope, or any optical instrument, intended to be used with both eyes simultaneously.

Binuclear (*bis* twice, and *nucleus*). A Nebula which has two condensed portions of light is said to be "binuclear."

Bisect (*bis* twice, *secare* to cut); to divide anything into two equal parts. Astronomically the word is most usually applied to the placing of the wires of a micrometer or similar instrument centrally over an object.

C.

Calendar, or *kalendar* (*kalendæ*, the first day of every month), is the name applied to the tabular statement of a system of reckoning time.

Canopus, a star otherwise called α Argûs.

Capella, a star otherwise called α Aurigæ.

Carina (keel), a portion of the constellation Argo, being the keel thereof.

Castor, a remarkable binary star, otherwise called α Geminorum.

Catoptrics (κάτοπτρον, a mirror); that division of the science of optics which treats of the formation of images by reflection.

Celbalrai, a star otherwise called β Ophiuchi.

Chaph, a star otherwise called β Cassiopeiæ.

Circle, great; any circle on a sphere, the plane of which circle passes through the centre of the sphere, and therefore divides the sphere into two equal parts.

Circle, Mural. See p. 696.

Circle, small; any circle on a sphere, the plane of which circle does *not* pass through the centre of the sphere, and therefore divides the sphere into two unequal parts.

Circle, Transit. See p. 680.

Circumpolar (*circum* around, and *Polus*); the two regions of the heavens lying near the North and South poles respectively. The word is also used to refer to those portions of the sky which at the place of observation are always above the horizon.

Clamp; a contrivance for making fast for a time certain parts of an instrument which are ordinarily moveable.

Clepsydra (κλέπτω I steal, and ὕδωρ water); a kind of Water-clock.

Clock-stars; certain stars usually em-

ployed for the regulation of clocks in an observatory, by reason of the fact that their positions have been very accurately determined.

Co-latitude, the complement of the latitude or what it wants of 90°.

Collimation, line of (*cum* with, and *limes* a limit); virtually the optical axis of a telescope.

Colures (κόλος clipped, and οὐρά a tail) are two great circles passing through the poles of the heavens at right angles to each other, the tail ends of which are always cut off, as it were. The equinoctial colure passes through the poles and equinox and corresponds to the hour circles of 0^h and 12^h of R.A., and the solstitial colure passes through the poles and solstices and corresponds to the hour circles of 6^h and 18^h of R.A.

Comes (*comes* a companion, plur. *comites*). The smaller of two stars forming a "Double-star" is often called the *comes* of the principal star.

Comet (κομήτης, hairy).

Cometarium, a mechanical toy invented by Desaguliers, and designed to indicate the motion of a comet or other body which follows an eccentric orbit.

Cometography (*comet*, and γράφω I describe); that branch of astronomy which treats specially of comets.

Commutation, angle of, the distance between the Sun's true place as seen from the Earth and the place of a planet reduced to the ecliptic.

Complement of an angle or arc, the difference between any angle and 90°.

Compression of the Poles of a planet (*cum* together, and *premere* to squeeze); the ratio in which the Polar diameter of a planet is shorter than the Equatorial, expressed as a fraction of the equatorial diameter. Thus the Polar diameter of the Earth being $\frac{299}{300}$ of the Equatorial the comparison is $\frac{1}{300}$.

Configuration, the relative positions of stars or other celestial bodies.

Conjunction (*cum* together, and *jungere* to join); two or more heavenly bodies are said to be in conjunction when they have the same longitude or right ascension.

Constant (*cum* together, and *stare* to stand); a numerical quantity always of the same value in a mathematical computation or in an astronomical reduction is called a constant. Thus the ratio of the circumference of a circle to its diameter is *constantly* about 3·1416 : 1, so, knowing the diameter, we can always determine the circumference.

Constellation (*cum* together, and *stella* a star); an assemblage of stars whose outline is conceived to represent some mundane object.

Cor Caroli, a star otherwise called α Canum Venaticorum.

Cor Hydræ, a star otherwise called α Hydræ.

Cor Leonis, a star otherwise called Regulus or α Leonis.

Cor Serpentis, a star otherwise called Unuk-al-hay or α Serpentis.

Cosmical (κόσμος, the world). A heavenly body is said to rise or set cosmically when it rises or sets at sunrise.

Co-tidal lines, imaginary lines running through different places on the Earth's surface where the tidal phenomena are the same at the same moment of time.

Crepuscular (*crepusculum*, the twilight), relating to or resembling the twilight.

Culmination (*culmen*, the top); the meridian passage of a heavenly body, which is then at the *top* of its course.

Cursa, a star otherwise called β Eridani.

Curtate distance (*curtare*, to shorten) is the distance of a planet or comet from the Sun or Earth projected upon the plane of the ecliptic.

Cusp (*cuspis*, a sharp point); the extremities of a crescent moon or inferior planet.

Cycle (κύκλος, a circle), a period within which a series of celestial phenomena recurs.

Cynosura (κύων, gen. κύνος a dog, and οὐρά a tail); a name occasionally given to the Polestar, notwithstanding that that star is placed at the end of the little *Bear's* tail.

D.

Declination (*declinare*, to bend); the angular distance of a heavenly body from the equator—symbol, δ. According as the declination is north or south, it is + δ or − δ.

Degree (*degredior*, to go down; from *de* down, and *gradus* a step). The circle is conventionally divided into 360 equal parts, each of which is called a degree.

Deneb, a star otherwise called α Cygni.

Denebola, a star otherwise called β Leonis.

Diameter (διά through, and μέτρον a measure); the breadth of anything.

Dichotomy (δίχα in two, and τέμνω I cut); a bisection. Applied to an inferior planet or the moon, it means the mo-

ment of quarter phase when the phase is a perfect semi-circle.

Differentiate, to fix the position of one celestial object by comparing it with another.

Digit (*digitus*, a finger); the twelfth part of the diameter of the Sun or Moon, a term used to express the amount of obscuration during a solar or lunar eclipse.

Dioptrics (διά through, ὄπτομαι I see); that division of the science of optics which treats of the formation of images which pass through transparent media.

Dip of the horizon, an allowance necessary to be made in reducing observations of altitude in cases where the observer's eye is elevated above the plane of the horizon. To find the Dip, multiply the square root of the height in feet by 58·795, and the product will be the dip in seconds of arc.

Disc (*discus*, a plate); the visible surface of the Sun, Moon, or planets.

Dubhe, a star otherwise called α Ursæ Majoris.

Dynamometer (δύναμις power, and μέτρον a measure); an instrument for measuring the magnifying power of lenses, &c.

E.

Eccentricity (ἐκ from, κέντρον a centre); the amount of the deviation of an elliptic orbit from a circle.

Eclipsareon, an astronomical toy invented by Ferguson to exhibit the phenomena of eclipses.

Eclipse (ἔκλειψις, a disappearance).

Ecliptic, the great circle of the heavens through which the Sun apparently makes a revolution in the course of a year, in consequence of the Earth's motion round that body. It derives its name from being the line on which eclipses of the Sun and Moon necessarily happen.

Ecliptic conjunction (see also *Conjunction*) is said to take place when two bodies have the same longitude, as the Sun and Moon at New Moon.

Egress (*egredior*, I step forth) is the passing off of an inferior planet from the disc of the Sun or of a satellite from the disc of its primary, at the end of the phenomenon known as a "transit."

Elements of an orbit (*elementum*, a first principle) are certain numerical quantities which define the path of a heavenly body through space.

Elevation of the Pole or of a celestial object is its angular height above the horizon, reckoned in degrees, &c. of arc.

Ellipse, one of the sections of a cone: popularly called an oval.

Ellipticity of a planet is the difference between its polar and its equatorial diameter due to the fact that it rotates on an imaginary axis passing through the poles.

Elongation (*longè*, afar off); the angular distance Eastward or Westward of an inferior planet from the Sun, or of a satellite from its primary.

Emersion (*emergere*, to come out); the re-appearance of an object after undergoing occultation.

Enif, a star otherwise called ε Pegasi.

Epact (ἐπί upon, and ἄγω I drive). A number used in forming the ecclesiastical calendar, and depending on the revolutions of the Earth and Moon.

Ephemeris (ἐπί for or during, ἡμέρα a day); a tabular statement of the positions of any planet or comet for any given series of days. [Prim. sig., but used generally for *any* table of positions.]

Epicycle (ἐπί on, and κύκλος a circle); a small circle having its centre on the circumference of a larger circle—a geometrical conception which is a leading feature of the Ptolemaic system of astronomy.

Epoch (ἐπέχω, I check?); the point of time to which any calculations are referred.

Equation; any number or quantity that has to be applied to the mean value of another number or quantity in order to obtain the true value.

Equation, personal; a term used in astronomy, and otherwise, to indicate some peculiarity personal to each of several observers, in virtue of which their estimates of time, for instance, differ *inter se* by some nearly constant regular amount.

Equation of equinoxes; the difference between the mean and apparent places of the equinox.

Equation of the centre; the difference between the true and mean anomalies of a planet or comet. Equal to 2ϕ. [See def. of eccentricity.]

Equation of time; the difference between mean and apparent time.

Equator (*æquus* equal, equally dividing the sphere), *celestial;* an imaginary prolongation of the equator of the Earth, and a circle frequently referred to in astronomy.

Equatorial instrument (literally, an instrument which moves in the equator),

Equinoxes (*æquus* equal, and *nox* night); the two points where the ecliptic intersects the equator, so called because on the Sun's arrival at either of them the day is equal to the night throughout the world.

Errai, a star otherwise called γ Cephei.

Etanin, a star otherwise called γ Draconis. This star, when passing the meridian at London, is very near the zenith.

Evection (*evehere*, to displace); a lunar inequality.

Exterior planets are those planets whose orbits lie outside that of the Earth.

F.

Falcated (*falx*, a sickle). The Moon or an inferior planet is said to be "falcated" when its illuminated portion is crescent-shaped.

Filar Micrometer (*filum*, a thread); a micrometer (q. v.) in which a thread of cobweb or fine wire is employed.

Focus (*focus*, a hearth = the central meeting place of a family); that point in which rays of light meet after having been either refracted or reflected.

Focus of an ellipse. See p. 40.

Fomalhaut, a star otherwise called α Piscis Australis.

G.

Galactic, having relation to the Milky Way.

Galaxy (γάλα, gen. γάλακτος milk); a name for the Milky Way.

Geocentric (γῆ the Earth, and κέντρον a centre); as viewed from, or having relation to, the centre of the Earth.

Geodesy (γῆ the Earth, and δαίω I divide); that branch of science which deals with the figure and dimensions of the Earth.

Gibbous (*gibbus*, hunched). When the illuminated portion of the Moon or a planet exceeds a semicircle, but is less than a circle, it is said to be gibbous.

Gnomon (γνώμων, an interpreter); the indicator of a sun-dial.

Gomeisa, a star otherwise called β Canis Minoris.

Gravity, terrestrial (*gravis*, heavy); the tendency inherent in all matter to fall towards the centre of the Earth.

H.

Hamal, a star otherwise called α Arietis.

Heliacal (ἥλιος, the Sun). A heavenly body is said to rise or set heliacally, when it first becomes visible in the morning after having been hidden by the Sun's rays, or when it first becomes lost in the Sun's rays in the evening.

Heliocentric (ἥλιος the Sun, and κέντρον the centre); as viewed from, or having relation to, the centre of the Sun.

Heliometer (ἥλιος the Sun, and μέτρον a measure); the absurd name of an instrument which is nothing more than a divided-object-glass micrometrical telescope.

Heliostat (ἥλιος the Sun, and ἵστημι I make to stand); an instrument used in surveying which retains a reflected ray of sunlight for some time in a fixed position, notwithstanding the apparent diurnal motion of the Sun. A form of the instrument specially intended for astronomical use is called a *siderostat*.

Hemisphere (ἡμι half, and σφαῖρα a sphere), a half-sphere; half the surface of the heavens. The celestial equator divides the celestial sphere into the Northern and Southern half-spheres, or hemispheres.

Homan, a star otherwise called ζ Pegasi.

Horary (*hora*, an hour); relating to an hour.

Horizon, artificial See p. 688.

Horizon (ὁρίζω, I bound or limit). The *sensible* horizon is that circle of the heavens which limits our view, and whose plane touches the Earth at the place of the observer, and is at right angles to the zenith. The *rational* (or *true*) horizon is parallel to the former, and passes through the centre of the Earth.

Hour angle, the distance of a heavenly body from the meridian, expressed in hours, minutes, &c.

I.

Immersion (*immergere*, to plunge into); the disappearance of an object before undergoing occultation.

Inclination (*inclinare*, to bend down, to slope); generally, the angle which one plane makes with another: in particular, one of the elements of the orbit of a planet or comet—namely, the angle which the plane of the orbit makes with the plane of the ecliptic.

Inequalities (*in* not, and *æquus* equal); conventionally applied to irregularities in the motions of planets.

Inferior planet, a planet whose orbit lies within that of the earth.

Ingress (*ingredior*, to enter) is the entrance of an inferior planet on to the

disc of the Sun or of a satellite on to the disc of its primary, at the commencement of the phenomenon known as a "transit."

Interior planets are those planets whose orbits lie within that of the earth.

Interstellar (*inter* in the midst, and *stella* a star). The interstellar regions of space are those parts of the universe which lie beyond the limits of the solar system.

Izar, a star otherwise called ε Boötis.

J.

Jovicentric (*Jupiter*, gen. *Jovis*, and κέντρον a centre); as viewed from, or having relation to, the centre of Jupiter.

K.

Kaus Australis, a star otherwise called ε Sagittarii.

Kochab, a star otherwise called β Ursæ Minoris.

Korneforos, a star otherwise called β Herculis.

L.

Latitude (*latitudo*, breadth); the angular distance of a heavenly body from the ecliptic, North or South as the case may be.

Libration (*librans*, swinging): an (apparent) oscillatory motion of the Moon.

Longitude (*longitudo*, length); the angular distance of a heavenly body from the first point of Aries measured on the ecliptic*.

Longitude, mean; the longitude of a planet or comet, supposing it to have moved with its mean (average) velocity.

Longitude, true; the real angular distance of a planet or comet from the first point of Aries.

Lucida (*lucidus*, bright); a word occasionally used in sidereal astronomy to indicate the brightest star of the constellation, or group, &c. mentioned.

Lumière cendrée (ash-coloured light).

Lunar (*luna*, the Moon); having reference to the Moon.

Lunation (*lunatio*, a change in the Moon); the period of the Moon's revolution round the Earth, in which it goes through all its phases, otherwise called its *synodic period*, or the lunar month.

M.

Major axis of an orbit of a planet or comet. See p. 43.

Malus (*malus*, a mast); a portion of the constellation Argo, being the mast thereof.

Markab, a star otherwise called α Pegasi.

Mass of a planet or comet is the quantity of matter contained in it: expressed either absolutely, as the weight in so many tons; or relatively, as such and such a fraction of the mass of the Sun, or some planet.

Mean distance of a planet or comet from the Sun is the mean of the extremes of the perihelion and aphelion distances; it is equal to half the longer axis of the ellipse, whence it is frequently termed the *semi-axis major*.

Mebsuta, a star otherwise called ε Geminorum.

Megrez, a star otherwise called δ Ursæ Majoris.

Menkalinan, a star otherwise called β Aurigæ.

Menkar, a star otherwise called α Ceti.

Meridian (*meridies*, mid-day); the great circle of the heavens passing through the zenith and the poles.

Micrometer (μικρός small, μέτρον a measure); an instrument for measuring small distances.

Minor axis of an orbit of a planet or comet. See p. 43.

Mintaka, a star otherwise called δ Orionis.

Mira (*mirus*, wonderful), a star otherwise called ο Ceti (= *Mira Stella*).

Mirach, a star otherwise called β Andromedæ.

Mirfak, a star otherwise called α Persei.

Mirzam, a star otherwise called β Canis Majoris.

Mizar, a star otherwise called ζ Ursæ Majoris.

Month, Nodical; the period in which the Moon passes from one of its nodes to the same node again.

Month, Sidereal; the period in which the Moon passes through the signs of the zodiac.

Moon-culminating Stars are certain stars which, being situated near the Moon, at any particular time are suitable points from which the angular distance of our satellite may be measured for the determination of the longitude of the place of observation.

* All our definitions have reference primarily to *res astronomicæ;* so it may be well to notify to the reader that some expressions (of which "longitude" is one) have a different signification in the vocabulary of geographers.

Motion, direct. A body is said to have a direct motion when it advances in the order of the signs, or when its longitude continually increases.

Motion, retrograde. A body is said to have a retrograde motion when it advances contrary to the order of the signs, or when its longitude continually diminishes.

N.

Nadir (*Arab. natara*, to correspond); the point immediately beneath an observer, and therefore exactly opposite the zenith.

Nath, a star otherwise called β Tauri.

Nebula (*nebula*, a fog).

Nekkar, a star otherwise called β Boötis.

Nocturnal arc, the arc of the heavens described by a celestial body during the night.

Node, longitude of the, is the angular distance of the place of the ascending node from the first point of Aries measured along the ecliptic.

Nodes (*nodus*, a knot) are those points in the orbit of a planet or a comet where it intersects the ecliptic. *The ascending node* (☊) is the point where the orbit passes from the South to the North side of the ecliptic; the *descending node* (☋) is the opposite point, where the orbit passes from the North to the South of the ecliptic. The imaginary line joining the nodes is called *the line of nodes.*

Nonagesimal degree of the ecliptic, otherwise called the *Medium Cœli*, is the ninetieth degree of the ecliptic, reckoned from its intersection with the Eastern point of the horizon at any time, and is therefore that point which is at its greatest altitude above the horizon.

Nova (*nova* [*stella*], a new star); a word introduced by Sir J. Herschel to signify a star or nebula not previously recorded.

Nucleus (*nucleus*, a kernel); the condensed portion of the head of a comet.

Nutation (*nutatio*, nodding); an oscillatory motion of the earth's axis.

O.

Oblate (*ob* against, *latus* borne). An oblate spheroid is obtained by compressing a sphere at its poles, and so causing it to bulge out at its equator; or an oblate spheroid may be defined as the solid figure generated by the revolution of an ellipse about its minor axis. If the ellipse revolves about its major axis the figure generated is a *prolate* spheroid.

Obliquity of the ecliptic (*obliquus*, slanting); the inclination of the plane of the ecliptic to the plane of the Equator.

Occultation (*occultare*, to hide); a general word applied in particular to the eclipse of planets and stars by the Moon.

Opposition. Two celestial bodies are said to be in opposition when their longitudes differ by 180°.

Orbit (*orbis*, a circle); the path of a planet or comet round the Sun; of a satellite round a primary; or of one double star round another.

Orientation (surveying term); the general direction of a chain of triangles. [Literally; the direction with respect to the East point.]

Orrery, an astronomical toy for exhibiting the motions of the planets round the Sun; so called in honour of an Earl of Orrery, who in the 18th century was a patron of Science.

P.

Parallactic Angle, see *Angle of Situation.*

Parallactic Inequality of the Moon. See p. 80.

Parallax (παραλλάξις, a change); a word variously applied in astronomy.

Parallax, Equatorial horizontal, of the Sun or Moon, is the angle subtended by the Earth's equatorial semi-diameter at the Sun or at the Moon.

Parallels of Declination are small circles parallel to the celestial equator.

Penumbra (*pene* almost, and *umbra* a shadow); the pale shade which encompasses the dark shadow of the Earth in an eclipse of the Moon.

Periastre (περί near, and ἄστρον a star): that point in the orbit of a binary star, at which the secondary star is nearest to its primary.

Perigee (περί near, γῆ the Earth); the converse of *apogee* (q. v.)

Perihelion (περί near, and ἥλιος the Sun); the converse of *aphelion* (q. v.)

Perihelion distance; the least distance of a planet or comet from the Sun, usually expressed in semi-diameters of the Earth's orbit. Symbol, q.

Perihelion, longitude of, is the angular distance of a perihelion from the first point of Aries; it is usually reckoned upon the ecliptic up to the node, and thence upon the orbit.

Perihelion passage is the moment of the arrival of a planet or comet at its least distance from the Sun.

Period (περί round, and ὁδός a path). Derivatively, period implies *space*, but it is used in reference to *time*.

Perisaturnium. The point in the orbit of a satellite of Saturn nearest the primary.

Perturbation (*perturbare*, to interfere with); the disturbance produced in the orbits of planets and comets by the effect of the attraction of other planets, &c.

Phact, a star otherwise called *α* Columbæ.

Phase (φαίνω, I appear); applied in particular to the different appearances of the Moon during a lunation.

Phecda, a star otherwise called *γ* Ursæ Majoris.

Photometer (φῶς light, gen. φωτός, and μέτρον a measure); an instrument for determining the relative intensities of different sources of light.

Planet (πλανήτης, a wanderer); certain solid bodies which revolve round the Sun.

Planet, secondary. See *Satellite*.

Planetarium, another name for *orrery* (q. v.).

Platonic year, the period occupied by the equinoxes in performing a complete revolution: about 25,000 years.

Polaris, a star otherwise called *α* Ursæ Minoris, so named from its situation in the heavens.

Pole (πολέω, I turn); the extremities of the imaginary axis upon which the sphere and planets are regarded as rotating.

Pollux, a star otherwise called *β* Geminorum.

Precession of the equinoxes (*præcedere*, to go before) is a slow retrograde motion of the equinoxes, due to the attraction of the Moon, Sun, and planets on the protuberant matter of the Earth's equator.

Prime Vertical; the great circle passing through the zenith and the East and West points of the horizon.

Procyon, a star otherwise called *α* Canis Minoris.

Prolate (*pro* forwards, *latus* borne), a prolate spheroid is obtained by compressing a rotating sphere at its equator, and so causing it to bulge out at its poles.

Puppis (poop), a portion of the constellation Argo, being the poop thereof.

Q.

Quadrant (*quadrans*, a fourth part), particularly the fourth part of a circle. An instrument so called was formerly used in astronomy and navigation, but it has been superseded in the one case by the transit circle, and in the other by the sextant.

Quadrature. When the Moon or an inferior planet is distant one quarter of a circle, or 90°, from the Sun, it is said to be in "quadrature" E. or W. as the case may be.

R.

Radiant Point, a term used to designate a point of the heavens from which it is an established fact that luminous meteors are accustomed to radiate. There are a large number of such points recognised.

Radius vector (literally a radius carrier); an imaginary line joining the Sun and the centre of a planet or comet in any part of its orbit. It is therefore a measure of the real distance of the latter from the former.

Ras-alhague, a star otherwise called *α* Ophiuchi.

Ras-algethi, a star otherwise called *α* Herculis.

Rate (applied to a clock); the change of its error from the correct time, whether sidereal or mean, during a period of 24 hours.

Reduction, the process of correcting an observation as actually made in order that it may be comparable with other observations. In reducing observations corrections may have to be applied for refraction, parallax, aberration, proper motion, epoch, clock error, and so on.

Refraction (*refrangere*, to bend); a change of direction in rays of light caused by the varying density of the medium through which the rays pass.

Regulus, a star otherwise called *α* or Cor Leonis.

Retrogradation, an apparent motion of the planets, in virtue of which they seem to go backwards in the ecliptic and to move contrary to the order of the signs.

Rigel, a star otherwise called *β* Orionis.

S.

Sad-al-melik, a star otherwise called *α* Aquarii.

Sad-al-sund, a star otherwise called *β* Aquarii.

Satellite (*satelles*, a companion); the orthodox name for what are often called moons and secondary planets; namely, the little bodies which re-

volve round certain of the major planets.

Saturnicentric (Saturn, and κέντρον a centre); as viewed from, or having relation to, the centre of Saturn.

Scheat, a star otherwise called β Pegasi. This name is also borne by δ Aquarii.

Schedar, a star otherwise called α Cassiopeiæ.

Scintillation (*scintilla*, a spark); a fastidious word applied to what everybody knows as the twinkling of the stars.

Secondary planet. See *Satellite*.

Sector, astronomical, an instrument for finding the distance between two objects whose distance is too great to be measured by means of a micrometer in a fixed telescope.

Secular (*seculum*, an age); a term usually applied to some variation in the elements of the orbit of a planet, which is too small to be conveniently taken account of for one year and which is therefore calculated for periods of 100 years each.

Secunda Giedi, a star otherwise called α^2 Capricorni.

Selenocentric (σελήνη the Moon, and κέντρον a centre); as viewed from, or having relation to, the centre of the Moon.

Selenography (σελήνη the Moon, and γράφω I describe), the branch of descriptive astronomy which treats specially of the Moon.

Semi-diurnal arc is the half of the arc described by any heavenly body between its rising and setting.

Sexagesimal, the division of the circle by *sixties*—the circumference into 360 equal parts called "degrees;" each degree into 60 "minutes;" and each minute into 60 "seconds."

Sextant (*sextans*, a sixth part); a well-known nautical instrument, so-called because its arc is the sixth part of a circle.

Sheliak, a star otherwise called β Lyræ.

Sheratan, a star otherwise called β Arietis.

Sidereal (*sidus*, a constellation); having relation to the stars.

Sign, the twelfth part of the circle of the ecliptic, or 30° thereof.

Sirius, a star otherwise called α Canis Majoris; the brightest star in the heavens. Anciently and often called the *Dog-star*.

Solar (*sol*, the Sun); having relation to the Sun.

Solstices (*sol* the Sun, and *stare* to stand still) are the two periods when the Sun reaches the northernmost and southernmost points of the ecliptic, so called because for a few days its declination does not seem to vary. The former is called the summer and the latter the winter solstice by the inhabitants of the Northern hemisphere.

Solstitial colure; the *colure* (q. v.) passing through the two solstitial points whose longitudes are 90° and 270° respectively.

Sothiac period; a period of 1460 years, at the completion of which, in consequence of the Egyptian year being taken at 365 days exactly, the days of the month return to the same seasons of the year.

Southing, the meridian passage of any object lying between the observer's zenith and the Southern horizon.

Speculum (*specere*, to look at); the reflector used in a reflecting telescope when such reflector is of *metal*.

Spica, a star otherwise called α Virginis.

Spring Tides, the high tides which happen about the times of New and Full Moon.

Stationary points (*stare*, to stand) of a planet's orbit are those points at which the planet appears to us to have no motion amongst the stars.

Sub-Polo, below the pole; applied to the passage of an object across the "lower" meridian.

Sulaphat, a star otherwise called γ Lyræ.

Superior planet, a planet whose orbit lies beyond that of the Earth.

Sweep, sweeping, terms introduced by Sir W. Herschel to describe his practice of surveying the heavens by clamping his telescope in successive parallels of declination, and allowing, during a series of equal intervals of time, portions of the sky to pass under view by the diurnal motion.

Symbols (σύμβολον, a token) are signs constantly used by all scientific men as abbreviations in writing, to save the constant repetition of the same words and phrases. I here give the astronomical and some of the chief mathematical ones :—

SIGNS OF THE ZODIAC.

Aries	♈
Taurus	♉
Gemini	♊
Cancer	♋
Leo	♌
Virgo	♍
Libra	♎
Scorpio	♏

Sagittarius	♐
Capricornus	♑
Aquarius	♒
Pisces	♓

The first, ♈, indicates the horns of the Ram; the second, ♉, the head and horns of the Bull. The barb attached to a sort of letter *m* designates the Scorpion; the arrow, ♐, sufficiently points to Sagittarius; ♑ is formed from the Greek letters *τρ*, the two first letters of *τράγος, a goat*. Finally, a balance, the flowing of water, and two fishes, may be imagined in ♎, ♒, and ♓, the signs of Libra, Aquarius, and Pisces [a].

THE SUN AND MAJOR PLANETS, &c.

The Sun	☉
Mercury	☿
Venus	♀
The Earth	⊕
The Moon	☾
Mars	♂
Jupiter	♃
Saturn	♄
Uranus	♅
Neptune	♆
A comet	☄
A star	✱

A hammer has been suggested for the supposed Intra-Mercurial planet Vulcan.

THE MINOR PLANETS.

Ceres	⚳
Pallas	⚴
Juno	⚵
Vesta	⚶

When the number of these bodies amounted to about 20 it was found impossible to continue to give them pictorial symbols; accordingly these symbols have been dropped, except the 4 earliest ones: all planets discovered subsequently being indicated by their ordinary number surrounded by a circle. Thus— (5) .. (72)

ELEMENTS OF ORBITS OF PLANETS AND COMETS.

M Mean anomaly.
λ or L Mean longitude at epoch.
ϖ Longitude of the perihelion.
☊ ν, Longitude of the ascending node.
ι, i, Inclination of orbit.
ϕ Angle of eccentricity.
ϵ Eccentricity (= Nat. sin. of ϕ).
μ, n, Daily mean motion, in seconds of arc.
a Semi-axis major, or mean distance.
T, τ, or PP Time of perihelion passage.
q Distance from Sun when in perihelion.
r Length of radius vector.
Δ Distance of the planet or comet from the Earth.

PLANETARY MOTIONS.

☊ Ascending node of an orbit.
☋ Descending node of an orbit.
☌ Two planets in *conjunction*: difference of longitude 0°.
⚹ Two planets in *sextile*: difference of longitude 60°.
□ Two planets in *quartile* or *quadrature*: difference of longitude 90°.
E. □ Eastern quadrature.
W. □ Western quadrature.
△ Two planets in *trine*: difference of longitude 120°.
☍ Two planets in *opposition*: difference of longitude 180°.

URANOGRAPHICAL.

R A. or Æ. or α, Right Ascension.
Decl. or δ, Declination: +, North; −, South.
N.P.D. North polar distance.
h. Hour.
m. Minute of *time*.
s. Second of time.
° Degree.
′ Minute of *arc*.
″ Second of *arc*.
‴ Third of *arc*. [obsolete.]
nf. North-following.
sf. South-following.
sp. South-preceding.
np. North-preceding.
Pos. Angle of position (of double stars).
Dist. Distance of two stars in seconds of arc.

LUNAR MOTIONS.

● Moon in conjunction, or *new*.
☽ Moon at Eastern quadrature, or *first quarter*.
○ Moon in opposition, or *full*.
☾ Moon at Western quadrature, or *last quarter*.

MATHEMATICAL.

+ Plus; sign of addition.
− Minus; sign of subtraction.
× Sign of multiplication.
÷ Sign of division.
± Plus-or-minus; "somewhere about."
= Sign of equality.
√ Square root.

[a] Arago.

∛ Cube root.
∠ Angle.
> Greater than.
< Less than.
∝ Varies as.
∞ Infinity.

Synodical (σύν with, and ὁδός a journeying). The synodical period of two bodies revolving round the same centre is the interval elapsing between the instant of their being together and the next time they occupy the same position.

Syzygy (σύν with, and ζυγόν a yoke); the conjunction and opposition of the Moon are both termed indifferently a syzygy.

T.

Talitha, a star otherwise called ι Ursæ Majoris.

Tangent-screw. A "tangent" to a circle being a straight line which touches the circle without cutting it anywhere, a "tangent-screw" is a screw which touches the edge of a circle belonging to an astronomical instrument, which, as it is furnished with teeth to secure the screw, has a slow motion of rotation imparted to it.

Tarazad, a star otherwise called γ Aquilæ.

Telescope (τῆλε far off, and σκοπέω I view).

Telescopic. A celestial object is said to be "telescopic" when a telescope of some sort is required for viewing it.

Temporary (*tempus*, time); lasting for a short time only.

Terminator (*terminus*, a boundary); the boundary line between the illuminated and the unilluminated part of the Moon's disc.

Thuban, a star otherwise called α Draconis.

Tide (*tidan*, to happen, Sax.); the periodical rising and falling of the waters of the Ocean.

Transit (*transire*, to go across). The optical passage of an inferior planet across the Sun, or of a satellite across its primary, or of a celestial body across the meridian.

Tropics (τρέπω, I turn).

U.

Ultra-zodiacal (*ultra* beyond, and zodiac); beyond the limits of the zodiac. A term sometimes applied to the minor planets, because their orbits (or at least many of them) reach beyond the zodiac.

Umbra (*umbra*, a shadow); the shadow of the Earth, Moon, or any other planet, is in particular so called.

Unuk-al-hay, a star otherwise called α Serpentis.

Uranography (οὐρανός the heavens, and γράφω I describe); that branch of astronomy which treats specially of the sidereal heavens.

Uranometry (οὐρανός the heavens, and μέτρον a measure); the measurement of the heavens: in Latin, *Uranometria*, and in that form the title of several well-known books.

V.

Vega, a star otherwise called α Lyræ: sometimes spelt Wega.

Velum (a sail), gen. plural *velorum*, a portion of the constellation Argo, being the sails thereof.

Vertex (*vertex*, the top or highest point of anything); a term used to designate that point in the limb of the Sun, the Moon, or of a planet, intersected by a circle passing through the zenith and the centre of the body.

Vertical circles, circles passing through the observer's zenith, and consequently through his nadir.

Via Lactea, the Latin word corresponding to the Greek "Galaxy" and the English "Milky Way."

Vindemiatrix, a star otherwise called ε Virginis.

Volume (*volumen*, bulk) of a planet or comet is its cubical contents, expressed either absolutely as so many cubic miles; or relatively as such and such a fraction of the Sun or some planet.

W.

Wasat, a star otherwise called δ Geminorum.

Z.

Zaurac, a star otherwise called γ^1 Eridani.

Zavijava, a star otherwise called β Virginis.

Zenith (Arabic), the point vertically over the head of the observer; in other words, the pole of the horizon.

Zenith distance, the complement of the altitude of a heavenly body; in other words, the angular distance of a heavenly body from the zenith.

Zodiac (ζώδιον, an animal); a belt of the heavens extending 9° on either side of the ecliptic, in which the Sun, Moon, all the major and many of the minor planets perform their annual revolutions.

Zosma, a star otherwise called δ Leonis.

Zuben-el-gubi, a star otherwise called α^2 Libræ.

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